METEOROLOGICAL OFFICE

ANNUAL REPORT 1973

HMSO: £1.10 net

Met O 872

ANNUAL REPORT
ON THE
METEOROLOGICAL OFFICE

1973

Presented by the Director-General
to the
Secretary of State for Defence

LONDON
HER MAJESTY'S STATIONERY OFFICE
1974

U.D.C.
551.5:06.055.5

© *Crown copyright* 1974

ISBN 0 11 400286 X

Cover photograph: The Hercules aircraft of the Meteorological Research Flight

FOREWORD BY THE DIRECTOR-GENERAL

During a year in which at least the weather was kind, the Meteorological Office was busier than ever. There was a marked increase in the demands for forecasts and other advice from industry and the general public, the number of direct inquiries to forecasting offices reaching an all-time record of 1·75 million. In addition 1·53 million forecasts were made for aviation and 1·55 million calls (a 20 per cent increase on 1972) were made on the Automatic Telephone Weather Service. The introduction of commercial radio, as with BBC local radio, promises to provide a valuable outlet for improving our services to the general public.

Weather-sensitive industries are becoming increasingly aware of the value of meteorological advice. In particular the necessity to conserve fuel and to forecast the demand as accurately as possible, together with more intensive exploitation of oil and gas in the North Sea, is likely to make increasing demands on the Office. There has also been a marked increase in work undertaken for the Army, both in providing services for Army aviation and advice in planning and operational tasks.

The main objectives of the Office are to produce weather forecasts of greater reliability and range and to ensure that they are disseminated and used as widely as possible. Hopes for further advances in weather forecasting rest mainly on the development of advanced mathematical models and good progress has been made in this field since the commissioning of the powerful IBM 360/195 computer in January 1972. The operational 10-level hemispherical model has been improved in several aspects during the year and is now performing considerably better than the earlier 3-level model especially in forecasting upper-air winds and temperatures and in providing forecasts of surface weather for up to 3 days ahead. A fine-scale version of this model, designed primarily to predict rainfall at 100-km intervals across Europe for up to 36 hours ahead, became operational in December. A new computational scheme which allows the fast-moving gravity waves to be treated by semi-implicit methods of integration has quartered the computing time for a 36-hour forecast from 48 to only 12 minutes. New methods of treating the vertical lapse rate of temperatures and deriving the vertical motion have led to improved predictions of the movement and development of depressions, of jet-stream speeds, and of rainfall.

However, the accuracy of weather forecasts, which forms the subject of a special article in this report, depends not only on the quality of the model and the available computer power but on an adequate supply of observations and here, despite the introduction of satellite observing systems, there is some cause for concern. The Office has always depended heavily on the excellent co-operation of voluntary observers to provide a good deal of its observations. Of the 268 regularly reporting stations in the U.K. only 91 are manned by staff of the Office; 72 are manned by coastguards and lighthouse keepers, 70 by staff of other public bodies, and 35 by private individuals, but changing social conditions make it increasingly difficult to maintain this voluntary effort and close the gaps left by the closure of Royal Air Force stations. At sea, observations are made at 6-hourly intervals by the British voluntary observing fleet of about 500 merchant ships but reductions in the numbers of ships at

sea and in the sizes of crews again make it difficult to maintain, much less expand, this effort. The recent withdrawal of the U.S. weather ships, the only source of reliable upper-air information over the western Atlantic, also gives cause for concern. Deterioration of the observational network may be partly checked by the installation of automatic weather stations on land, ships and buoys, and the first two of a batch of 10 are now undergoing operational trials. However, the voluntary effort will remain indispensable for many years to come and I can only appeal to our dedicated observers to continue their good and much appreciated work.

As part of a continuing programme of automation, high-quality plotted and line-drawn weather charts are now being produced by automatic techniques for operational use and these will increasingly replace manual methods during the coming year. Good progress has been made in transferring meteorological archives from obsolete magnetic tapes and from tens of millions of punched cards to magnetic tape readable by the IBM 360/195 computer, and in building up efficient and easily accessible synoptic and climatological data banks.

Treasury approval has been obtained to enhance the large computer next year with a front-end processer. This will relieve the main central processer of many of its control functions and of most of the small computing tasks, thereby effectively doubling its capacity to handle the large numerical forecasting models. The new processer, a powerful computer in its own right, will also be able to produce numerical forecasts at reduced speed should the main computer be out of action. Arrangements have also been made to rent a high-speed electronic interface between the large computer and the smaller computers that control parts of the telecommunication system. From mid 1974 this will enable most of the observations from the Global Telecommunications System, after automatic checking and correction, to flow directly into the main computer for objective analysis and forecasting.

The project concerned with making continuous measurements of rainfall over the Chester Dee catchment by radar continues to make good progress. Results so far obtained demonstrate the potential superiority of the radar system over a fairly dense network of rain-gauges, especially in showery situations. The radar method is subject to rather large errors when the radar beam intersects the level at which snow melts into rain, but it should be possible to reduce this and other errors by using a shorter wavelength and therefore a narrower beam, and the radar has now been modified accordingly.

In the research field, considerable effort continues to be devoted to the development of models to simulate and perhaps predict the behaviour of the atmosphere on relatively long time-scales. A 5-level model is being used to simulate developments on a hemispherical or global scale over periods of 100 days. The effects of monthly and seasonal changes in the input of solar energy have been studied and some progress made with the difficult problem of incorporating radiative processes and their interaction with clouds. It has been demonstrated that anomalies in sea surface temperature can have important and far-reaching effects on the development of weather patterns. In particular, one very interesting experiment strongly suggests that an important factor in producing the very cold European winter of 1962/63 was an area of abnormally warm ocean off West Africa.

A new 11-level model with 10 000 grid points at each level and covering the entire globe was introduced during the year. The first experiments that started from an observed situation showed that the model followed the actual atmospheric behaviour very well over a 7-day period. A limited-area version

of this model is being developed for use in tropical regions, and will make use of the data to be collected during the Atlantic Tropical Experiment (GATE) in 1974. Another version of the model, extended to 13 levels, is also being developed to allow simulation of the stratospheric circulation. The first experiment with this model was particularly interesting in that it produced a development remarkably similar to the 'sudden warmings' observed in the upper atmosphere at the end of winter. Provision is now being made for the introduction into this model of the photochemistry of ozone and other minor constituents with the object of making the first satisfactory study of the combined effects of the air motions and the photochemical processes on the concentrations of ozone in the stratosphere.

The production of oxides of nitrogen in the stratosphere by supersonic transport aircraft and their possible effects on the concentration of ozone at high levels have aroused considerable controversy. Calculations made by Meteorological Office scientists indicate that the quantities of nitrogen oxides injected into the stratosphere by nuclear-test explosions in the 1950s and 1960s were equivalent to those likely to be produced by 1000 Concordes each flying 7 hours a day. Moreover analysis of the world-wide ozone records taken before and after the nuclear explosions fails to reveal any detectable ehanges in the total ozone content of the atmosphere.

The Meteorological Office collaborated with France, the U.S.A. and the U.S.S.R. in comparison trials held at the Kourou Range in French Guiana of rockets designed to measure winds and temperatures up to heights of 70 km (see Plates VI and VII, upper). The data obtained with 12 SKUA rockets showed good agreement with those of France and the U.S.A. but the temperatures measured by the Russian rockets were considerably lower than the others above 40 km. The Kourou data and similar data obtained from 24 rockets fired from Gan, Indian Ocean, last Autumn show substantial fluctuations in the winds and temperatures in the middle and high levels of the tropical atmosphere over periods of less than 12 hours.

The preliminary design work on a remote atmospheric temperature sounder to be carried by the next generation of U.S. operational meteorological satellites has been successfully concluded, and a contract has been placed with a U.K. firm which will lead to the construction of flight models of a pressure-modulated radiometer to be delivered to the U.S.A. from 1976–77 onwards.

The Hercules aircraft, which has been undergoing extensive modifications to convert it into a flying laboratory, was delivered to the Meteorological Research Flight at the end of the year (see Plates I–III). Fitted with an inertial platform, probes for measuring atmospheric turbulence, weather radar, a dropsonde facility, a wide range of instruments for research in cloud physics, radiation etc and an on-board data-processing system, it is probably the best equipped meteorological research aircraft in the world. Its first major task will be to participate in the Atlantic Tropical Experiment during June–September 1974 when it will operate from Dakar. During January–March 1973, the Canberra aircraft took part in a joint research project with the National Center for Atmospheric Research, Boulder, to measure the momentum fluxes in waves generated over the Colorado mountains.

Turning now to international matters, a new upper-air station was installed in Tarawa in the Gilbert Islands (see Plate VII, lower) and the station at Funafuti resumed operations after destruction by a storm in 1972. Both these stations have been established to meet requirements of the World Weather Watch in the south-west Pacific and are operated by the meteorological

services of Australia and New Zealand on behalf of the Meteorological Office.

The Convention for the European Centre for Medium-range Weather Forecasts was signed in Brussels on 11 October and the Director is expected to take up his appointment early in 1974. Until a new building is provided in the grounds of the Meteorological Office College at Shinfield Park, Reading, the Centre will be accommodated in Bracknell and work closely with the Office.

Public interest in the work of the Office continued unabated. I was pleased to receive a large number of distinguished visitors from home and many other countries during the year. Organized visits by parties from universities, schools and the general public reached a record total of 104, and 19 more visits were arranged for representatives of the Press and broadcasting organizations. It was quite impossible to meet all the requests for lectures and tasks from outside bodies, but over 150 lectures were given voluntarily by members of staff during the year.

The year 1973 has been outstandingly successful for the recruitment of graduates, and over 30, including 15 Ph.D.s, have been appointed. Unfortunately recruitment of support staff has not been so successful, and the Office has suffered from an increasing shortage of Assistant Scientific Officers.

B. J. MASON

January 1974
Meteorological Office,
Bracknell, Berks.

CONTENTS

	Page
FOREWORD BY THE DIRECTOR-GENERAL	iii
FUNCTIONS OF THE METEOROLOGICAL OFFICE	viii
COMMITTEES	ix
PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE	xi
METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION	xiv
DIRECTORATE OF SERVICES	
Special topic—The evaluation of weather forecasts	1
Forecasting services	12
Climatological services	26
Hydrometeorology	28
Services for agriculture	32
Observational requirements and practices	33
Operational instrumentation	39
Computing and data processing	46
Systems development	50
Meteorological telecommunications	54
International and planning	62
Summary of weather of 1973	64
Statistics	75
DIRECTORATE OF RESEARCH	
Special topic—Research on the structure of the lowest kilometre of the atmosphere	83
Physical research	89
Dynamical and synoptic research	98
General activities of the Research Directorate	106
Professional training	107
Library, Publications and Archives	109
Statistics	111
INTERNATIONAL CO-OPERATION	113
STAFF	
General	121
Honours and distinctions	122

APPENDICES

I. BOOKS OR PAPERS BY MEMBERS OF THE STAFF	123
II. A SELECTION OF THE LECTURES AND BROADCASTS GIVEN BY MEMBERS OF THE STAFF	131
III. PUBLICATIONS	138

FUNCTIONS OF THE METEOROLOGICAL OFFICE

The Meteorological Office is the State Meteorological Service. It forms part of the Air Force Department of the Ministry of Defence. The Director-General is responsible to the Secretary of State for Defence through the Parliamentary Under-Secretary of State for Defence for the Royal Air Force.

The general functions of the Meteorological Office are:

(a) The provision of meteorological services for the Army, Royal Air Force, Civil Aviation, the Merchant Navy and Fishing Fleets.

(b) Liaison with the Director of Meteorology and Oceanographic Services (Naval) and provision of basic meteorological information for use by the Royal Navy.

(c) The provision of meteorological services to other government departments, public corporations, local authorities, the Press, television, radio, industry and the general public.

(d) The organization of meteorological observations, including observations of radiation and atmospheric electricity, in the United Kingdom and at certain stations overseas.

(e) The collection, distribution and publication of meteorological information from all parts of the world.

(f) The maintenance of the observatories at Kew and Lerwick.

(g) Research in meteorology and geophysics.

The Meteorological Office also takes a leading part in international co-operation in meteorology. The Director-General is the Permanent Representative of the United Kingdom with the World Meteorological Organization.

Except for the common services provided by other government departments as part of their normal functions (e.g. accommodation by the Property Services Agency of the Department of the Environment, and stationery by Her Majesty's Stationery Office) the cost of the Meteorological Office is borne by Defence Votes.

The gross expenditure on the Meteorological Office, including that on the common services, was approximately £15·4 million in 1973. Of the amount chargeable to Defence Votes, about £9·0 million represents expenditure associated with staff and £6·0 million expenditure on stores, communications and miscellaneous services. Some £2·9 million was recovered from other government departments and outside bodies in respect of services rendered, sales of meteorological equipment etc.

COMMITTEES

METEOROLOGICAL COMMITTEE

Terms of reference:

(a) To keep under review the progress and efficiency of the Meteorological Service and the broad lines of its current and future policy.
(b) To keep under review the general scale of effort and expenditure devoted to the meteorological services.
(c) To ensure the maintenance of adequate contacts between the Meteorological Service and those who use its services.

Membership at 31 December 1973:

Chairman: The Earl of Halsbury, F.R.S.

Members: Professor R. L. F. Boyd, C.B.E., F.R.S. (Chairman, Meteorological Research Committee) (*ex officio*)
Professor A. H. Bunting, C.M.G.
Sir Frederic Harmer, C.M.G.
Sir Arthur Hetherington, D.S.C.

Secretary: Mr H. E. Davies (Secretary, Meteorological Office)

The Committee met four times in 1973.

ADVISORY COMMITTEE ON METEOROLOGY FOR SCOTLAND

Terms of reference:

(a) To review the development of meteorological science and its application to Scotland.
(b) To submit to the Meteorological Committee any proposal in connection therewith.

Membership at 31 December 1973:

Chairman: Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)

Members: Dr H. E. Butler, F.R.S.E. (Royal Society of Edinburgh)
Sir Samuel C. Curran, F.R.S. (Royal Society)
Professor S. Desmond Smith, F.I.P., F.R.S.E. (Heriot-Watt University)
Mr G. S. Lawrie (Department of Agriculture and Fisheries for Scotland)
Professor H. Meidner (University of Stirling)
Professor P. A. Sheppard, C.B.E., F.R.S. (Royal Meteorological Society)
Mr J. W. Shiell (Scottish Development Department)
Dr J. H. Steele (Department of Agriculture and Fisheries for Scotland)
Professor D. W. N. Stibbs, F.R.S.E. (University of St Andrews)
Professor P. A. Sweet (University of Glasgow)

Secretary: Mr D. R. Grant (Meteorological Office)

The Committee met once in 1973.

METEOROLOGICAL RESEARCH COMMITTEE

Terms of reference:

The Meteorological Research Committee will advise the Parliamentary Under-Secretary of State for Defence for the Royal Air Force on the general lines along which meteorological and geophysical research should be developed within the Meteorological Office and encouraged externally. It shall review progress and report annually.

It is empowered to appoint subcommittees, one of which shall be responsible for advising on the use of money allocated annually from Defence Votes for research projects conducted outside the Meteorological Office. The Committee will be responsible for co-ordinating the work of its subcommittees.

Membership at 31 December 1973:

Chairman: Professor R. L. F. Boyd, C.B.E., F.R.S.

Members: Mr J. K. Bannon, I.S.O. (Director of Services, Meteorological Office)
Instructor Captain J. A. Bell, R.N. (Director of Meteorology and Oceanographic Services (Naval))
Professor H. Charnock
Professor D. R. Davies
Dr E. R. R. Holmberg (Army Department)
Dr J. T. Houghton, F.R.S.
Mr R. F. Jones (Deputy Director, Physical Research, Meteorological Office)
Mr E. Knighting (Deputy Director, Dynamical Research, Meteorological Office)
Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)
Mr F. O'Hara (Procurement Executive, Ministry of Defence)
Professor R. P. Pearce, F.R.S.E.
Mr J. S. Sawyer, F.R.S. (Director of Research, Meteorological Office)
Mr A. E. Seddon (Natural Environment Research Council)
Professor P. A. Sheppard, C.B.E., F.R.S.
Professor R. C. Sutcliffe, C.B., O.B.E., F.R.S.
Wing Commander N. E. Wilkins, D.F.C. (Air Force Department)

Secretary: Mr F. E. Dinsdale (Meteorological Office)

The Committee met twice in 1973 and its subcommittees seven times.

PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE

DIRECTOR-GENERAL

B. J. Mason, C.B., D.Sc., F.R.S.

DEPUTY TO THE DIRECTOR-GENERAL

J. S. Sawyer, M.A., F.R.S.

DIRECTORATE OF SERVICES

DIRECTOR	J. K. Bannon, I.S.O., B.A.
INTERNATIONAL AND PLANNING	
Assistant Director	D. G. Harley, B.Sc.

FORECASTING SERVICES

DEPUTY DIRECTOR	M. H. Freeman, O.B.E., M.Sc.
CENTRAL FORECASTING	
Assistant Director	G. R. R. Benwell, M.A.
Chief Forecasting Adviser	T. H. Kirk, B.Sc.
Special Post	R. Dixon, B.Sc.
DEFENCE SERVICES	
Assistant Director	E. Evans, M.Sc.
H.Q., Strike Command	R. A. Buchanan, M.A.
PUBLIC SERVICES	
Assistant Director	L. Sugden, B.Sc.
London/Heathrow Airport	R. E. Farms, B.Sc.

COMMUNICATIONS AND COMPUTING

DEPUTY DIRECTOR	G. A. Corby, B.Sc.
TELECOMMUNICATIONS	
Assistant Director	E. J. Bell, C.Eng., M.I.E.E.
DATA PROCESSING	
Assistant Director	G. A. Howkins, M.B.E., B.Sc.
SYSTEMS DEVELOPMENT	
Assistant Director	E. J. Sumner, B.A.

OBSERVATIONAL SERVICES

DEPUTY DIRECTOR	N. Bradbury, B.Sc.
OBSERVATIONAL REQUIREMENTS AND PRACTICES	
Assistant Director	L. S. Clarkson, M.Sc.
Marine Superintendent	G. A. White, Captain, Extra Master
CLIMATOLOGICAL SERVICES	
Assistant Director	P. F. Illsley, B.Sc.
AGRICULTURE AND HYDROMETEOROLOGY	
Assistant Director	R. Murray, M.A.
Special Post	L. P. Smith, B.A.
OPERATIONAL INSTRUMENTATION	
Assistant Director	M. J. Blackwell, M.A.

DIRECTORATE OF RESEARCH

DIRECTOR	J. S. Sawyer, M.A., F.R.S.

PHYSICAL RESEARCH

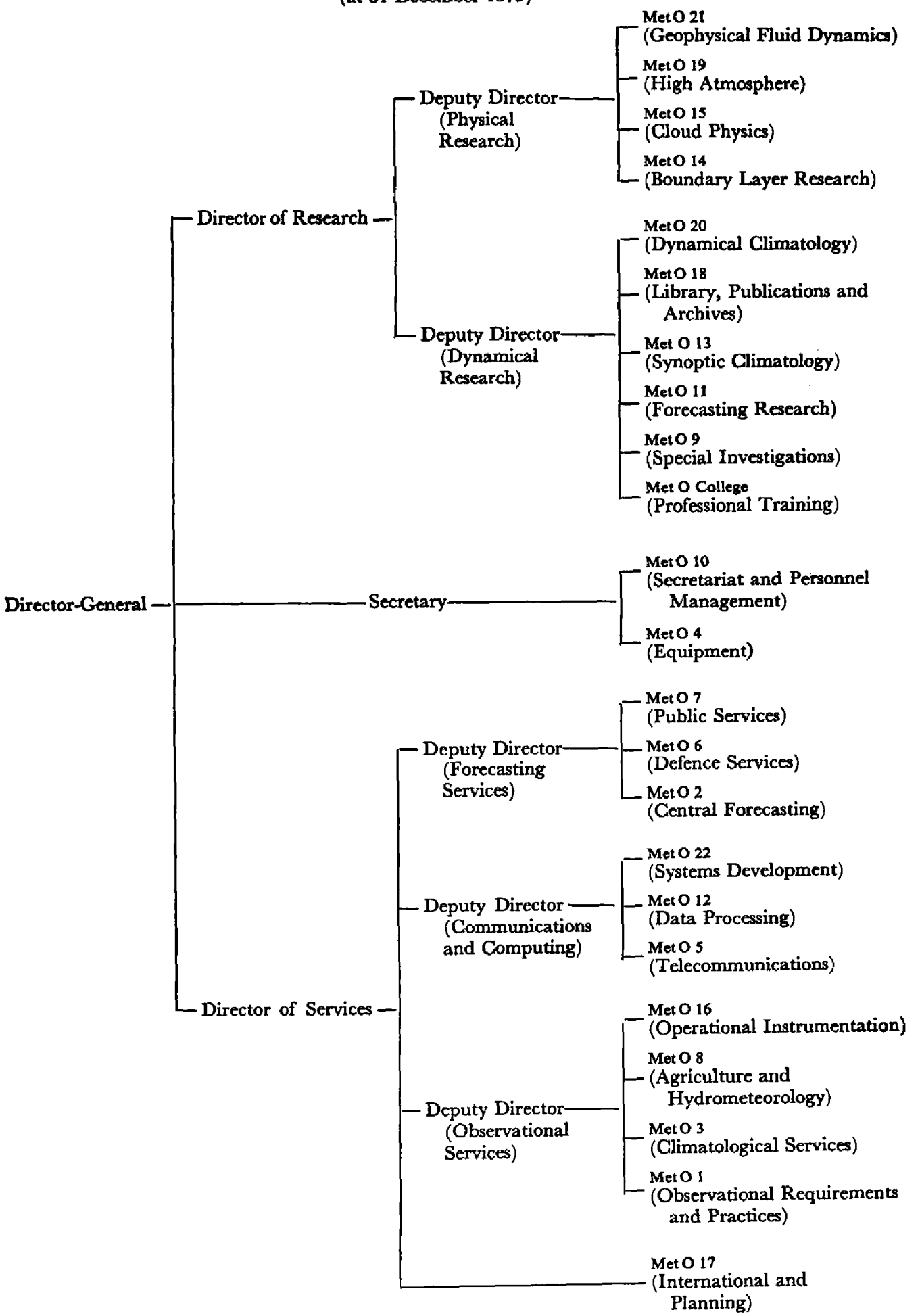
DEPUTY DIRECTOR	R. F. Jones, B.A.
BOUNDARY LAYER RESEARCH	F. Pasquill, D.Sc.
GEOPHYSICAL FLUID DYNAMICS LABORATORY	R. Hide, Sc.D., F.R.S.
METEOROLOGICAL RESEARCH FLIGHT	D. G. James, Ph.D.
CLOUD PHYSICS	
Assistant Director	P. Goldsmith, M.A.
Special Post	K. A. Browning, Ph.D., D.I.C.
HIGH ATMOSPHERE	
Assistant Director	N. E. Rider, D.Sc.
Special Post	K. H. Stewart, Ph.D.

DEPUTY DIRECTOR	E. Knighting, B.Sc.
SPECIAL POST	R. J. Murgatroyd, O.B.E., Ph.D., C.Eng., M.I.E.E.
SPECIAL INVESTIGATIONS	
Assistant Director	J. Briggs, B.A.
FORECASTING RESEARCH	
Assistant Director	F. H. Bushby, B.Sc., A.R.C.S.
SYNOPTIC CLIMATOLOGY	
Assistant Director	R. A. S. Ratcliffe, M.A.
Special Post	J. M. Craddock, M.A.
PROFESSIONAL TRAINING	
Assistant Director and Principal, Meteorological Office College	D. H. Johnson, M.Sc., A.R.C.S.
DYNAMICAL CLIMATOLOGY	
Assistant Director	A. Gilchrist, M.A.

SECRETARY, METEOROLOGICAL OFFICE	H. E. Davies, M.A.
PERSONNEL MANAGEMENT	W. D. S. McCaffery, B.Sc.

METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION

(at 31 December 1973)


Director-General
Secretary
Met O 10 (Secretariat and Personnel Management)
Met O 4 (Equipment)
Director of Research
Deputy Director (Physical Research)
Met O 21 (Geophysical Fluid Dynamics)
Met O 19 (High Atmosphere)
Met O 15 (Cloud Physics)
Met O 14 (Boundary Layer Research)
Deputy Director (Dynamical Research)
Met O 20 (Dynamical Climatology)
Met O 18 (Library, Publications and Archives)
Met O 13 (Synoptic Climatology)
Met O 11 (Forecasting Research)
Met O 9 (Special Investigations)
Met O College (Professional Training)
Director of Services
Deputy Director (Forecasting Services)
Met O 7 (Public Services)
Met O 6 (Defence Services)
Met O 2 (Central Forecasting)
Deputy Director (Communications and Computing)
Met O 22 (Systems Development)
Met O 12 (Data Processing)
Met O 5 (Telecommunications)
Deputy Director (Observational Services)
Met O 16 (Operational Instrumentation)
Met O 8 (Agriculture and Hydrometeorology)
Met O 3 (Climatological Services)
Met O 1 (Observational Requirements and Practices)
Met O 17 (International and Planning)

THE DIRECTORATE OF SERVICES

Special Topic—The Evaluation of Weather Forecasts

Introduction

The general public is rightly interested in the accuracy of weather forecasts. The utility or usefulness of forecasts is less frequently mentioned, yet both accuracy and utility are important if forecasts are to be used to maximum advantage. The term 'evaluation' covers both these aspects and it is convenient to distinguish between 'verification' in which the emphasis is on the degree of goodness or perfection of the forecasts, irrespective of their application and 'operational evaluation', in which the forecasts are judged in terms of their value or utility to the user. Verification of forecasts is undertaken within the Meteorological Office, as a routine activity, primarily to provide an overall measure of performance which may be expected to indicate the effectiveness of the forecasting methods and to monitor the effects of changes which are introduced from time to time. The interest of the Meteorological Office in operational evaluation derives from the desire to give the best and most helpful advice to the user and from the need to assess the economic value or benefit of meteorological forecasts to different sections of the community.

Forecasts may be of many kinds. Most people are interested exclusively in the forecasts expressed in words and disseminated by television, radio and the Press. For specialists, forecast information may be presented by means of processed data on a chart or alternatively in numerical form using, for example, a computer-to-computer link. Meteorologists themselves make great use of prognostic charts on which the expected distributions of atmospheric pressure and other meaningful parameters are depicted by means of isopleths valid for some future time. Charts of this kind are the basis of nearly all weather forecasts. For this reason an assessment of their accuracy forms a useful starting point. There is the added advantage that these forecasts can be evaluated to some extent by simple and relatively objective statistical parameters. Forecasts expressed in words have to be assessed subjectively and the results are inevitably less precise and more difficult to interpret.

The verification of prognostic charts

(a) *Surface charts.* Forecasts issued to the public of the weather to be expected at the earth's surface during the following 24 hours are largely based on forecast charts of the distribution of atmospheric pressure at the surface. Over a period of many years, a systematic evaluation has been made of the 24-hour prognostic charts issued by the Central Forecasting Office by comparing the forecast height of the 1000-mb pressure surface at 48 (6×8) points (see Figure 1) with the corresponding heights on the 'actual' or verifying chart. From the pressure distribution it is possible to derive quite easily the 'geostrophic' winds and the accuracy of these is also evaluated. Of the many statistics that are calculated to express different aspects of the association between forecast and actual values, the most practical, convenient and meaningful indices are the mean height error or 'bias', the root-mean-square (r.m.s.) height error, and the root-mean-square (r.m.s.) vector wind error which takes account of errors in both the

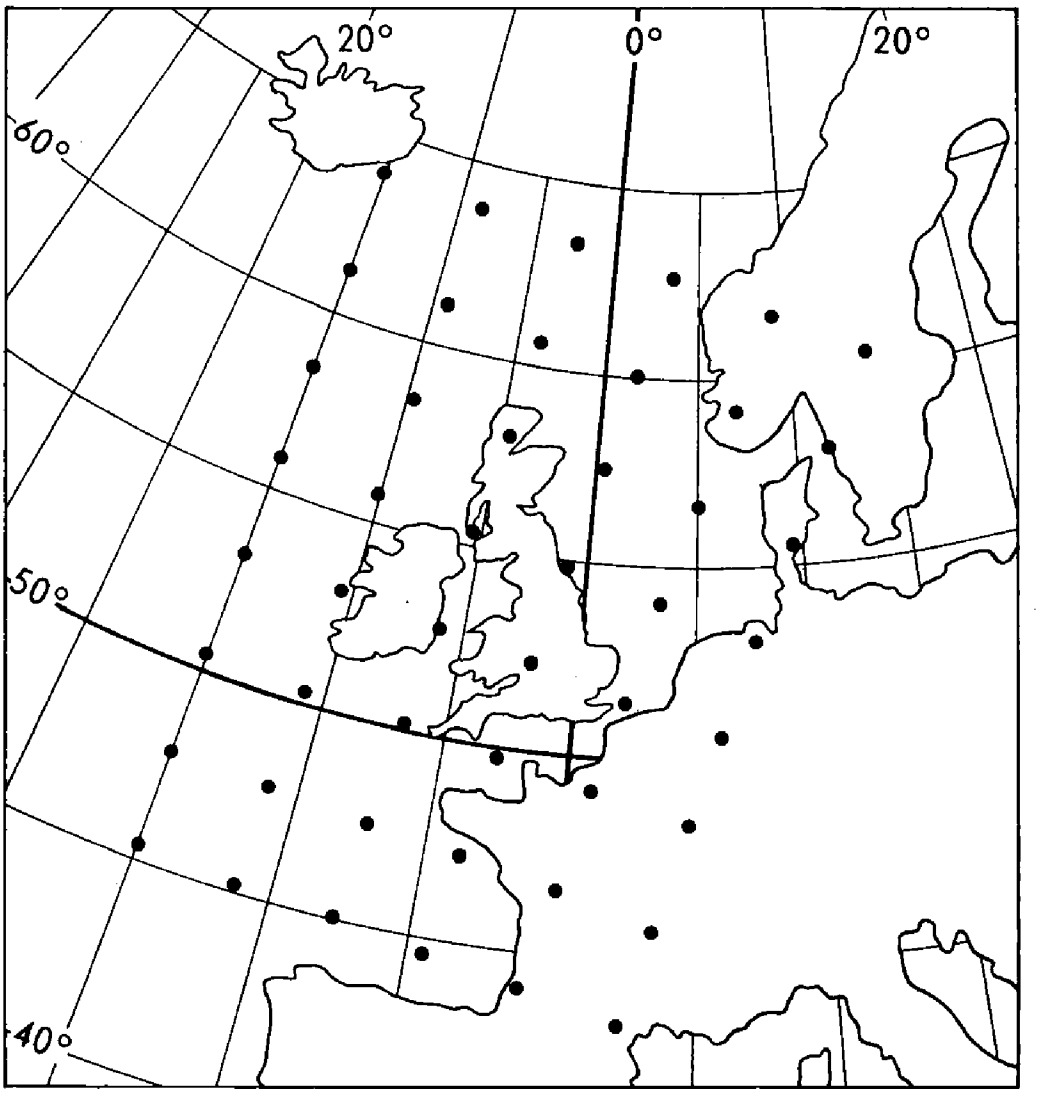


FIGURE 1—48–POINT GRID FOR THE ROUTINE EVALUATION OF SURFACE PROGNOSTIC CHARTS

speed and direction of the wind. Yearly summaries of these statistics for the period 1957–73 are shown in Table 1. They show remarkably little change over the years which indicates that the standard of surface prognostic charts produced subjectively by the human forecaster reached a plateau some years ago with little hope of further improvement.

Since 1966 objective numerical forecasts of pressure, wind and temperature fields (or closely related quantities) have been made on a routine basis by computer. Until mid 1972 these mathematical forecasts were based on a very simplified model of the atmosphere represented by only 3 levels in the vertical (the surface, about 20 000 ft and 40 000 ft) but which, nevertheless, produced forecasts of the broad distribution of the meteorological parameters and the evolution of major weather systems that soon rivalled the traditional products and led to an early decision to produce upper-air forecasts for aviation entirely by computer. The 3-level model did not, however, include the hydrological cycle and so could not contribute to the forecasting of cloud, rain and snow and these elements had still to be dealt with by the human forecaster. Following the commissioning of the powerful new IBM 360/195 computer in January

TABLE 1—VERIFICATION OF 24-HOUR SURFACE PROGNOSES FOR 00 GMT—YEARLY SUMMARY

Year	r.m.s. height error *metres*	Mean height error *metres*	r.m.s. vector wind error *knots*
1957	45	− 8	16
1958	44	−12	16
1959	46	−12	17
1960	43	−11	16
1961	45	−10	17
1962	45	− 8	17
1963	43	−10	16
1964	42	− 8	15
1965	44	− 8	16
1966	44	− 9	16
1967	44	− 9	16
1968	43	−11	15
1969	42	−10	15
1970	42	− 9	16
1971	43	− 5	16
1972	43	− 5	16
1973	42	− 5	16

1972, little time was lost in introducing a much more complex 10-level model of the atmosphere covering practically the whole of the northern hemisphere with much improved representation of the physical processes including the hydrological cycle, and this became fully operational in August 1972. An important contribution of the computer methods has been to improve the reliability of forecasts from 24 to 72 hours. Table 2 shows the errors in the surface pressure and wind fields produced by unmodified computer forecasts for 24, 48 and 72 hours ahead. Comparison with Table 1 shows that these errors are rather less than those of the traditional subjective forecasts. In respect of internal consistency and coherence, the numerical 24-h forecast is superior to the subjective forecast but the main defect of the numerical product is the large mean height (pressure) error which increases progressively as the forecast period is extended. This seems to be a deficiency of all numerical forecasting models but it does not significantly affect the pattern of the pressure distribution on which the winds and weather depend.

Since 1967, subjective verifications have been made of the 48 and 72-h surface forecasts produced by the medium-range forecaster using the computer products for both the surface and 500 mb ($\approx$20 000 ft) as guidance. Forecasts were classified using the following criteria:

A. Good guidance—a good forecast in all important aspects.

B. Not correct in all details but did not lead to any serious error over the U.K.

C. Misleading in some important aspect.

The results, displayed in Table 3, show that the accuracy of both the 48 and 72-h forecasts has improved since 1967. The improved performance has been partly due to the skill developed by the medium-range forecasters and their concentration on this particular task and also on the adoption of a more critical approach to the interpretation of the computer products.

TABLE 2—VERIFICATION OF COMPUTED 00 GMT SURFACE FORECASTS—YEARLY SUMMARY

Year	r.m.s. height error *metres*	Mean height error *metres*	r.m.s. vector wind error *knots*
24-h computer forecasts			
1968	37	−14	13
1969	37	−14	13
1970	38	−16	13
1971	38	−16	13
*1972	36	−10	13
1973	33	−12	12
6 Years	37	−14	13
48-h computer forecasts			
1969	66	−32	18
1970	67	−37	19
1971	67	−36	18
*1972	60	−21	18
1973	57	−20	18
5 Years	64	−30	18
72-h computer forecasts			
1969	88	−50	21
1970	92	−54	22
1971	93	−53	22
*1972	80	−28	22
1973	78	−23	22
5 Years	86	−42	22

* From August 1972 the statistics apply to the 10-level numerical model.

TABLE 3—EVALUATION OF 48-HOUR AND 72-HOUR SURFACE FORECASTS

	48-h forecast			72-h forecast		
	A	B	C	A	B	C
	per cent			*per cent*		
1967	24	51	25	7	50	43
1968	36	43	21	16	46	38
1969	50	36	14	29	38	33
1970	56	35	9	30	40	30
1971	52	39	9	28	47	25
1972	51	37	13	27	45	28
1973	47	36	17	18	39	43

A – essentially correct—good guidance.
B – did not lead to any major error over U.K.
C – misleading in some important aspect.

(b) *Upper-air charts.* The earlier 3-level numerical model and especially the current 10-level model have proved markedly superior to subjective methods in forecasting winds and temperatures at upper levels for aviation. All such forecasts are now done by computer methods; numerical values of the forecast parameters are fed directly from the Meteorological Office computer into the airline computers for flight planning and also provide the basis of the meteorological advice (flight documentation) issued to aircrews. Since computer methods were introduced in 1966, the r.m.s. vector errors in the 24-h forecast winds at 500 mb (≈20 000 ft) and 200 mb (≈40 000 ft) are almost halved from about 30 knots to only about 16 knots and the 48-h forecasts are now as good as the 24-h forecasts were a decade ago. Table 4 shows the r.m.s. vector

wind errors produced by the 3-level model based on comparisons made at 560 grid points over an area stretching from the Great Lakes to the Ural Mountains. Below the line are shown the corresponding statistics for the new 10-level model which show a significant improvement over the 3-level model. The 10-level model also produces better forecasts of the location and strength of jet streams.

TABLE 4—ROOT-MEAN-SQUARE VECTOR WIND ERRORS IN THE FORECASTS OF THE NUMERICAL LEVEL MODELS—YEARLY SUMMARY

	1000 mb		500 mb		200 mb	
	T+24	T+48	T+24	T+48	T+24	T+48
	knots		*knots*		*knots*	
1967	15	21	17	25	20	31
1968	15	20	17	25	20	29
1969	15	20	17	25	20	29
1970	15	20	18	26	20	29
1971	15	21	19	27	20	30
Sept. 1972–Dec. 1973 ...	13	15	16	23	20	27

Verification of written (BBC) forecasts

Whereas objective numerical tests can be devised to assess the accuracy of forecast charts, it is much more difficult to assess written forecasts which are largely descriptive. Here the approach has to be more subjective than for the numerical products. Nevertheless, it is important to make assessments of the forecasts issued to the general public and to do this on a continuing and comparable basis in order to monitor performance and check standards. Although much thought has been given to the evaluation of public-service forecasts in several countries, and some elaborate schemes have been proposed, none has commanded widespread confidence and acceptance. The difficulty lies in deciding what weights should be given to the various elements of the forecast in arriving at an overall figure of merit for the forecast as a whole. Although it is possible to design sensible systems of awarding 'skill-scores' for individual parameters such as temperature, wind, precipitation etc., it is much more difficult to combine these individual marks into an overall score for the forecast as a whole. This is mainly because the weighting of the various factors will be judged differently by different users and should probably vary with season and climatic regime. Thus a forecast which gets high marks for temperature and wind but is a few hours out in predicting the arrival of a rain belt may be regarded as a complete failure by a farmer concerned with getting in the harvest whilst a yachtsman or a power engineer may judge it more leniently. Or, to take another example, an error of a few degrees in the forecast minimum temperature may be unimportant and pass almost unnoticed in midsummer, but a similar error may have very serious consequences when the temperature is near freezing.

Since August 1963 the Meteorological Office has employed a simple marking scheme to the 0755 BBC forecast valid for the following 16 hours, and the 1755 forecast valid for the following 30 hours. The forecasts for each of the seven regions are checked by selected Meteorological Office stations within the region. Each forecast is evaluated in terms of four parameters—wind (speed and direction), weather, state of sky, and maximum temperature—each being awarded marks 2, 1, or 0 according to whether the forecast is regarded as

correct, only partly correct, or incorrect. The evaluators are encouraged to look at the matter from the point of view of an interested layman (e.g. a farmer, fisherman etc.) and therefore the rules governing the allocation of marks are as few and as simple as possible. In Table 5 these marks are reduced to a percentage of the total marks possible and the results for each element are averaged for all the regions and summarized for each year. The overall result obtained by taking

TABLE 5—VERIFICATION OF BBC REGIONAL FORECASTS AS A PERCENTAGE OF POSSIBLE SCORE

Year	Forecast issed at 0755						Forecast issued at 1755				
	Wind	Weather	Sky	Max. temp.	Together	Wind	Weather	Sky	Max. temp.	Together
	per cent							*per cent*		
1963–64	82	79	85	87	83	74	72	78	83	77
1964–65	83	81	85	88	84	74	72	78	83	77
1965–66	82	80	86	87	84	73	71	78	84	77
1966–67	85	80	85	88	84	75	72	78	84	77
1967–68	85	82	86	86	85	74	74	80	82	77
1968–69	84	82	87	85	85	75	74	81	81	78
1969–70	83	80	85	85	83	73	72	79	80	76
1970–71	83	84	86	87	85	73	75	79	82	77
1971–72	84	82	85	87	85	75	74	78	83	77
1972–73	84	85	87	86	85	75	78	80	82	79
10-year mean ...	83	81	86	87	84	74	73	79	82	77

an average of the marks for the different elements has little more than formal significance and avoids the difficulties mentioned above of assigning different weighting factors to the various elements. The following comments can be made on the results of Table 5:

(a) Although the marking is carried out by many different stations and individuals, there is a high degree of uniformity between the different regions.

(b) The scores are much the same for the four different elements so that taking a simple average for the overall result seems sensible and does not distort its significance.

(c) The 0755 forecast, as might be expected, is consistently more reliable than the 1755 forecast, the overall scores being 84 and 77 per cent respectively.

(d) The overall results show little change over the 10-year period.

The regional forecasts for 0755 and 1755, issued by regional offices, are themselves based on guidance given by the Central Forecasting Office, Bracknell in country-wide 'Synoptic Reviews' issued some 2½ hours earlier. A check on these Synoptic Reviews was introduced in November 1967 with assessments made as follows:

A. Forecast correct in all important details and gave good guidance.

B. Forecast incorrect in some details but no major error.

C. Misleading in some important aspect—a major error.

Table 6 gives these markings in percentages for each month during the years 1968–73. It shows that less than 10 per cent of these forecasts are subject to major errors. The improvement over the last 3 years is quite noticeable. An analysis of the main types of major error is given in Table 7. More than half of these are failures to predict the onset and duration of rain and snow. Hitherto the computer models have been unable to predict these features and this is probably the main reason why there has been very little improvement in the accuracy of forecasts issued to the general public since the introduction of computer methods. However, a new 10-level model with finer resolution and covering Europe and the North Atlantic, and designed to predict rainfall at 100-km intervals on the ground for up to 36 hours ahead is about to come into operation and is expected to make improvements in the forecasting of surface weather.

Operational evaluation

In view of the widespread use of weather forecasts by industry and the general public, the Meteorological Office is concerned not only with their scientific assessment but also with their utility and economic value to the customer. Besides the 1½ million forecasts issued each year for aviation, the Office deals with more than 1½ million inquiries from industry and the public. About 250 000 of these come from the marine industry, 150 000 from agriculture, 150 000 from public utilities and 100 000 from building and construction. Many of the forecasts and other forms of advice are tailored to the special problems and requirements of the user. The requirements of some of the more important weather-sensitive industries and the extent to which they can be met are described below.

(a) *Agriculture.* Agriculture is perhaps the most weather sensitive of all the major industries and farmers are in general well aware of the advantages to be gained from taking meteorological advice. About 10.5 per cent of the total of non-aviation weather inquiries and about 11.8 per cent of the climatological inquiries are concerned with agriculture. The BBC weather broadcasts, particularly the outlooks for the following 2 or 3 days, constitute the main basis of short-term advice to farmers and some account of their accuracy has already been given. Although forecasts for a day or two ahead are valuable in making tactical decisions on such operations as harvesting, hay-making etc., farmers would welcome extended forecasts for a week or so ahead to help them plan their work (e.g. sowing, harvesting, irrigation, crop-spraying) on a longer time-scale. An attempt is made to assist them by a BBC Sunday television broadcast in which the weather outlook is given for a week ahead. Table 8 shows the results of a trial of 7-day forecasts produced on an experimental basis (but not issued to the public). The assessments, which are made by an independent team of meteorologists not concerned with producing the forecasts, show that the forecasts show evidence of skill up to about 5 days. Further progress in this field awaits the extension of reliable computer forecasts from 3 days to at least 5 days and these may well be achieved within a few years.

(b) *Aviation.* The Meteorological Office has been closely involved with aviation for more than 50 years. Forecasts of upper winds and temperatures for much of the northern hemisphere are required by civil and military operations for pre-flight and in-flight planning. The accuracy requirements

TABLE 6—ASSESSMENT OF SYNOPTIC REVIEWS (ISSUED AT 0425 GMT AND 1525 GMT)

	1968			1969			1970			1971			1972			1973		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	per cent			*per cent*			*per cent*			*per cent*			*per cent*			*per cent*		
January	26	57	17	55	34	11	35	47	18	48	44	8	56	31	13	63	32	5
February	53	41	6	57	39	4	59	27	14	47	45	8	73	24	3	73	20	7
March	47	39	14	68	31	1	52	34	14	53	37	10	63	30	7	76	22	2
April	60	33	7	65	22	13	52	38	10	57	36	7	73	24	3	77	18	5
May	54	31	15	47	39	14	45	47	8	61	37	2	69	31	0	73	22	5
June	43	47	10	40	50	10	58	39	3	72	25	3	60	25	15	70	18	12
July	60	22	18	64	26	10	61	36	3	71	24	5	65	32	3	58	37	5
August	74	20	6	47	32	21	57	25	18	72	26	2	68	27	5	54	43	3
September	28	60	12	52	35	13	62	28	10	70	25	5	83	12	5	68	24	8
October	47	40	13	53	42	5	52	40	8	73	27	0	81	17	2	53	45	2
November	37	36	27	53	33	14	45	45	10	67	33	0	67	28	5	87	10	3
December	43	44	13	43	47	10	67	28	5	74	24	2	69	28	3	67	31	2
Mean	48	39	13	54	35	11	54	36	10	64	32	4	69	26	5	68	27	5

A — good guidance.
B — did not lead to any major error.
C — misleading in some important aspect.

TABLE 7—MAJOR ERRORS IN SYNOPTIC REVIEWS ISSUED AT 0435 GMT AND 1435 GMT FOR PERIOD 22 NOVEMBER 1967 TO 31 OCTOBER 1973 (TOTAL 4342 FORECASTS)

Number of cases in total of 4342 forecasts	Type of error	Percentage of total of major errors
76	Timing of fronts—quicker than expected ...	13
75	Rainfall—underestimated	13
50	Timing of fronts—slower than expected ...	9
45	Rain—more widespread than expected ...	8
44	Rain—not forecast	8
40	Development of wave disturbances—not forecast	7
29	Rain forecast—did not materialize	5
19	Development in wrong area/position	3½
15	Snow—not forecast	2½
15	Thunderstorm activity—not forecast	2½

The table lists errors in descending order of incidence and includes all types that occurred on more than 10 occasions.

TABLE 8—EXPERIMENTAL 7-DAY FORECASTS FOR PERIOD 17 SEPTEMBER 1968 TO 31 DECEMBER 1973 (TOTAL 190 FORECASTS)

	Day 4	Day 5	Day 6	Day 7
	per cent			
GOOD FORECAST				
(No serious error over U.K.)	58	49	35	34
MINOR ERROR				
(Significant error over part of U.K.)	33	40	42	33
MISLEADING				
(Major error(s) over much of U.K.)	9	11	23	33

for civil aviation are set by the International Civil Aviation Organization (ICAO); they are: upper-air temperatures within ± 3 degC on 90 per cent of occasions and upper winds (at levels above 25 000 ft) within 20 knots vector difference on 90 per cent of occasions over a period of one hour's flying time. Table 9 shows the r.m.s. vector errors in the 24-h and 48-h forecasts of winds at the 500 mb ($\approx$20 000 ft) and 200 mb ($\approx$40 000 ft) levels produced by the 10-level computer model since it came into operation in August 1972. Table 10 shows the corresponding errors in the predictions of temperature. The errors are the differences between the numerical predictions of spot values and actual observations for 28 radiosonde stations spread across western Europe. The r.m.s. errors in the 24-h forecasts for the whole 16-month period average 1·9 degC and 16 knots at 500 mb and 3·6 degC and 21 knots at 200 mb. Since errors evaluated along 500-mile tracks (equivalent to about one hour's flying) are considerably less than those for particular points, it seems likely that the ICAO requirements are now near to being satisfied and monitoring tests are being made to check that this is so.

(c) *Public utilities.* The electricity and gas industries are very weather sensitive and make much use of tailor-made forecasts to estimate customer demands. Each of the 12 Area Gas Boards receives forecasts of 2-hourly temperatures and 4-hourly winds six times a day, and forecasts for up to 3 days ahead, of daily maximum and minimum temperatures twice a day. All the grid control centres of the Central Electricity Generating Board receive 12-hourly forecasts of temperature, wind, cloud, rainfall and lightning risk four

TABLE 9—ROOT-MEAN-SQUARE VECTOR WIND ERRORS IN THE 10-LEVEL MODEL (OCTAGON VERSION)

		1000 mb*		500 mb		200 mb	
		T+24	T+48	T+24	T+48	T+24	T+48
		knots		*knots*		*knots*	
Jan.	1973	12	14	19	27	23	34
Feb.	1973	13	15	18	26	20	29
Mar.	1973	12	15	16	23	17	23
Apr.	1973	13	15	17	24	17	24
May	1973	11	14	15	20	17	22
June	1973	11	13	15	21	20	27
July	1973	10	12	12	16	15	20
Aug.	1973	10	12	13	17	20	28
Sept.	1972	11	13	14	21	20	27
	1973	12	15	15	21	19	26
Oct.	1972	13	15	17	24	20	28
	1973	13	15	15	23	19	28
Nov.	1972	14	17	17	25	23	31
	1973	15	19	18	27	21	28
Dec.	1972	14	16	18	25	21	29
	1973	16	20	20	29	21	32

* Results for the 1000-mb level are biased to the extent that only when the surface pressure is greater than 1000 mb can the forecast be compared with actual observations.

TABLE 10—ROOT-MEAN-SQUARE TEMPERATURE ERRORS IN THE 10-LEVEL MODEL (OCTAGON VERSION)

		1000 mb*		500 mb		200 mb	
		T+24	T+48	T+24	T+48	T+24	T+48
				degrees Celsius			
Jan.	1973	5·9	6·5	2·0	3·3	4·4	5·1
Feb.	1973	4·0	4·8	2·2	3·5	3·5	4·7
Mar.	1973	3·6	4·8	1·7	2·7	3·4	4·9
Apr.	1973	3·7	4·5	2·2	3·5	3·3	3·9
May	1973	2·7	3·3	1·8	2·5	3·6	4·7
June	1973	2·6	3·2	1·8	2·5	3·8	4·9
July	1973	2·8	3·5	1·5	1·9	3·6	4·2
Aug.	1973	2·9	3·7	1·6	2·4	3·0	4·3
Sept.	1972	3·3	4·0	1·8	3·0	3·8	4·9
	1973	3·2	3·8	1·7	2·4	3·5	4·2
Oct.	1972	4·1	4·7	1·8	2·7	4·2	5·3
	1973	3·0	3·8	1·8	3·2	3·0	3·9
Nov.	1972	4·2	4·6	2·2	3·5	3·9	5·1
	1973	3·4	4·7	2·3	3·6	3·5	4·1
Dec.	1972	6·1	6·6	2·0	2·9	3·8	4·9
	1973	3·3	4·4	2·3	3·5	4·0	4·4

* Results for the 1000-mb level are biased to the extent that only when the surface pressure is greater than 1000 mb can the forecast be compared with actual observations.

times a day; a 24-h forecast each afternoon to predict demand for the next day; and a 3-day forecast on Fridays to plan maintenance work over the weekend. With the help of this information the CEGB keeps its spinning reserve capacity down to 700 megawatts which is equivalent to the additional load imposed by a 1-degC drop in temperature across the whole country.

A recent study provides information on the accuracy of short-period temperature forecasts issued by the London Weather Centre to the Gas Board. Table 11 shows the accuracy of forecasts for periods of 4 to 24 hours from the

time of origin for the year March 1972–February 1973. It shows the percentage of forecasts correct within ± 1 degC (the desirable accuracy for predictions of gas demand), correct within ± 2 degC, and of extreme errors $\geqslant 5$ degC. To provide a standard for comparison, similar percentages are given for 24-h persistence, i.e. the assumption that the temperature will be equal to that at the corresponding time during the preceding 24 hours. It will be seen that 90 per cent of the 12-h forecasts are correct within ± 2degC with less than 1 per cent being in error by more than 5 degC, the corresponding figures for 24-h forecasts being 78 per cent and 4·4 per cent respectively. It is also clear that the forecasts are much more accurate than persistence up to 12 hours ahead but are only slightly better than persistence at 24 hours.

TABLE 11—ACCURACY OF TEMPERATURE FORECASTS 4 TO 24 HOURS FROM TIME OF ORIGIN

	Forcast			Persistence	
Hours ahead	% correct within $\pm$ 1 deg C	% correct within $\pm$ 2 deg C	% errors $>$ 5 deg C	% correct within $\pm$ 2 deg C	% errors $>$ 5 deg C
4	80	94	0	75	4·9
8	73	91	0·5	77	4·1
12	69	90	0·8	76	5·8
16	68	88	1·1	75	4·9
20	61	82	1·9	76	4·9
24	51	78	4·4	72	5·2

(d) *Weather routeing for shipping.* A weather routeing service for ships on the North Atlantic trade has been provided by the Meteorological Office since March 1968 and was recently extended to the North Pacific. The object of the service is to enable ships to reach their destination in the shortest possible time, commensurate with the avoidance of damage to the ship and cargo.

This is an activity which at first sight appears suitable for operational evaluation in that definite objectives are specified and performance can be assessed against them. In practice, however, neither of the two main objectives, saving of time and avoidance of damage, is a sufficient measure or criterion in itself. Some shipping companies are primarily concerned with a saving of crossing time but not exclusively so in that heavy damage must be avoided. Other companies are less interested in time-saving and more concerned to avoid damage of any kind. Only the individual company is in a position to assess the optimum balance for its particular type of operation. Ideally, this balance can only be quantified in terms of cash-saving and this is the ultimate criterion. Since this information is not available to the Meteorological Office, it is only possible to present performance in terms of time-saving without having regard to the damage avoidance aspect. Table 12 gives information on time-savings during 1970–73 which have averaged about 6 hours on an Atlantic crossing.

Summary. The evaluation of forecast charts, which can be assessed by objective methods, shows that the errors in the 24-h forecasts of winds and temperatures in the upper air up to heights of 40 000 ft have decreased by at least 50 per cent since the introduction of computer methods in 1966 and the 48-h forecasts are now as good as the 24-h forecasts were a decade ago. The current standards of accuracy largely satisfy the requirements of civil aviation except in the vicinity of jet streams and areas of sharply-changing gradients.

TABLE 12—WEATHER ROUTEING EVALUATION (ATLANTIC)

Year	Total vessels routed	Arrived on or ahead of time	Arrived late	Average time saved *hours*	Average extra distance due to routeing *miles*
1970	315	276	39	6	58
1971	197	170	27	9	91
1972	248	216	32	7	73
1973	218	162	56	2	54
Mean	244·5	206	38·5	6	67

Weather forecasts issued to the public are also largely based on forecast charts of atmospheric pressure, wind and temperature at the earth's surface and these, too, have shown improvements since the introduction of computer models. In particular, there has been a marked improvement in the accuracy of 48 and 72-h forecasts since 1967.

Written forecasts, such as those broadcast by the BBC, are more difficult to evaluate than numerical forecasts and the assessments have to be largely subjective. Of the 24-h national forecasts issued by the Central Forecasting Office for the guidance of the outstations the fraction containing serious errors has fallen to only 10 per cent in recent years. Regional forecasts, which cover smaller areas and attempt more detail, are rather less accurate. 84 per cent of the regional forecasts broadcast at 0800 for the following 16 hours, and 77 per cent of these issued at 1800 for the following 30 hours are judged by independent meteorological stations in the regions to be basically correct with no serious error. About half of the serious errors are failures to predict the timing of rain and snow. The number of failures has not changed significantly during recent years, perhaps not surprisingly, because until very recently the computer models were unable to contribute to the forecasting of precipitation.

It is hoped that the new 10-level computer models will lead to improvements in the forecasting of surface weather comparable to those already achieved in upper-air forecasting, and allow, in the not too distant future, useful forecasts to be made for at least a week ahead.

FORECASTING SERVICES

Central Forecasting Office

Bracknell is a Regional Meteorological Centre (RMC) within the framework of World Weather Watch (WWW). The latter is a concept ratified by the Congress of the World Meteorological Organization (WMO), whereby the meteorologically more advanced nations assist the less advanced. This assistance is achieved by the establishment of three World Meteorological Centres at Washington, Moscow and Melbourne, and by a number of RMCs. The Central Forecasting Office (CFO) at Bracknell has undertaken to meet stated needs o various National Meteorological Centres (NMCs) in Europe for regional forecasts. This it does by the preparation, for wireless-telegraphy and radiofacsimile transmission, of analysis and forecast charts covering a large area of the North Atlantic, Europe and the Arctic.

In addition to its role in the World Weather Watch, CFO is also the chief forecasting office for the National Meteorological Service and the ways in which it supports this role as well as that of an RMC are described fairly fully below.

The year 1973 was one of consolidation in CFO, following the considerable changes which occurred in 1972. The new accommodation has needed little modification since it was taken over in 1972, and the Central Forecasting Office, housed above the telecommunication centre and the computing laboratory, continues to be admired by the numerous visitors both from home and abroad.

The coarse-mesh version of the 10-level numerical forecasting model, which covers an octagonal area embracing much of the northern hemisphere, and which became operational in August 1972, has been modified in some particulars as a result of continued research and scrutiny by the Forecasting Research Branch, working closely with CFO. One of the main requirements of this 10-level model, namely the provision of forecasts of upper winds and temperatures to meet the needs of civil aviation planning and flight control, has been adequately met. The monthly evaluation statistics for 1973 supported the preliminary results for 1972 which indicated that the 10-level model provided rather more accurate navigational winds over the North Atlantic and the European/Mediterranean sectors than hitherto.

The basic sequence of procedures in use at Bracknell to produce forecasts for periods of up to 72 hours ahead has remained unaltered during the year 1973; this sequence was described fully in the *Annual Report* 1972. However, some mention should be made of the back-up procedures which are now available. In addition to the forecasts required for operational purposes from each forecast run, other forecasts with validity times extended by 12 hours are also produced and these are therefore available for use to cover a temporary computer breakdown involving the loss of only one forecast run. When such forecasts have to be used operationally it is convenient to refer to this procedure as the normal back-up mode of operation. For longer breakdowns on the computer, or when it seems possible that the breakdown might involve the loss of two or more forecast runs, arrangements have been made for the integrations to be carried out on a comparable computer now installed in the Rutherford Laboratory, Harwell, using the data tapes assembled at the telecommunication centre, Bracknell.

Increasing use was made in the forecast room of the visual display unit which provides the forecasters with the means whereby they can directly interrogate the computer store to obtain a visual presentation of recent reports or the latest forecast; this information can consist of pressure fields, upper-air charts, tephigrams or observations and it is possible to call for restricted parts of the forecast or analysed charts to obtain a greater chart magnification. Such a versatile piece of equipment is expected to provide even greater support in the future. As there are sometimes areas of relatively sparse data, especially when the cut-off times are largely determined by the need to produce the forecasts in time to meet specific deadlines, it is important that there is some provision in the system for a forecaster to add essential late data, or corrected data. It is envisaged that such intervention may be more easily achieved by use of the visual display unit than by other means and program development has taken place to achieve this; these programs, though well advanced, were not fully developed for operational use during 1973.

The Calcomp 1670 high-speed microfilm plotter located in the computing laboratory was put to greater use during 1973 and the line-drawn charts and tephigrams produced from this facility were very suitable for facsimile trans-

mission. The acquisition of two drum plotters and the testing of the programs needed to produce automatically plotted charts proceeded steadily during the second half of 1973 and in the last two months it was possible to make some use within CFO of these charts.

It was fortunate that the need to introduce automation into the plotting procedures had been foreseen some years ago and that earlier unfulfilled hopes had not led to the abandonment of such a scheme. The staff shortages towards the end of 1973 would have led to a considerably reduced service to outstations and NMCs who depend upon the facsimile transmissions from CFO had it not been possible to cover some of the plotting duties within CFO by means of these automatically plotted charts.

The main tasks imposed on CFO remain much as in recent years though naturally every effort is made to use to a greater extent the facilities provided by the computing laboratory. The procedures for the production of the synoptic data banks from the input of basic data were kept constantly under review and updated to allow for improved data handling. Better analyses could then be produced; these are essential to a modern forecasting service based on numerical forecasts derived from sophisticated atmospheric models such as the 10-level model. Further extensive work and trials have been carried out as a preliminary to the introduction of a comprehensive three-dimensional scheme of objective analysis. The ultimate aim, however, is the development of a satisfactory four-dimensional analysis scheme which could incorporate data made at non-standard times, such as aircraft wind reports, and vertical temperature profiles derived from infra-red radiation measurements from satellites.

Computer analyses and prognoses other than at the surface are issued in unmodified form on a number of facsimile land-line and radio circuits, both to domestic and to foreign recipients. Monitoring of the upper-air prognoses is carried out, however, and modifications are made during the production of flight documentation for civil aviation. This is usually confined to adjustments of the computed jet stream in the light of the most recent observational data available. Analyses of the stratosphere at 70, 50, 30 and 10 mb have been produced by computer program since early 1973, rendering unnecessary the need for manual production.

One of the primary tasks of the Senior Forecaster is to provide guidance to the outstations of the Office, mainly by means of charts depicting actual and forecast surface synoptic conditions augmented by advisory texts covering the next two or three days.

The advisory texts issued by the Senior Forecaster are supplemented by telephone conferences with staff of some of the major outstations responsible for producing forecasts for all or some part of the United Kingdom. Such conferences are frequently held with the staff of London Weather Centre, which is responsible for extempore television and radio broadcasts for the whole country. Conferences are also held regularly with the staff of the offices at Gloucester and Prestwick in relation to the expected weather over Wales and Scotland respectively.

CFO provides routine forecasts for sea and land areas and issues notifications of expected specified weather such as fine spells, or warnings of hazardous conditions. These statements are intended primarily for dissemination by the Press and radio, but some are issued direct to public utilities such as the Central Electricity Generating Board (CEGB) and to industry. The hazardous con-

ditions for which warnings are issued include gales for land and sea areas, fog, snow, icy roads, thunderstorms, frost, thaw, strong upper winds and ice accumulation on ship superstructures. Notifications are also issued for expected periods of propitious weather such as three-day periods of fine weather, specifically intended for the agricultural community.

Analyses and forecasts of wave heights and directions are produced as routine by computer for the North Atlantic area, for periods up to 48 hours ahead. These are broadcast, after suitable modifications to accord with later information, as a WWW requirement for the benefit of other European maritime nations and of ships at sea. They are also a basic requirement of the ship-routeing service provided by CFO, described under 'Services for marine activities'.

Cloud photographs from the automatic picture transmission (APT) of the United States weather satellites have continued to be received by direct interception at Bracknell daily. They are a routine aid in the preparation of surface analyses over the North Atlantic and European areas. Interpretations of the cloud information of these pictures (nephanalyses) are prepared and issued as routine to outstations by land-line and radio-facsimile. The nephanalyses are based on the pictures from all the accessible orbits, and are of considerable value to the outstations in their day-to-day work, e.g. for aircrew briefing. In addition some major forecasting offices and one research section receive APT pictures direct from the Bracknell receiving station by telephone line. The APT unit at CFO is responsible for adding the geographical grid to the pictures and for transmitting it to these selected outstations, so that they can locate the cloud pictures geographically.

The plotting and analysis of ice conditions in the northern hemisphere has continued and regular broadcasts are made to assist navigation in waters subject to sea ice, as well as to assist other meteorological services. During the polar spring and summer the APT pictures mentioned above are of considerable value in delineating the edges of the main icefields, though the resolution is insufficient to depict individual icebergs. The ice charts also show sea surface temperature isotherms. Separate charts of sea surface isotherms are also issued daily for the coastal waters of the British Isles.

The possibility of developing techniques for producing forecasts of a sufficiently acceptable standard for up to seven days ahead is still being pursued and, though regular forecasts are made experimentally and some success has been achieved, it is not yet sufficient to warrant publication of the forecasts.

A subsection of CFO has been responsible for some years for the development of programs required for operational numerical forecasting and as mentioned earlier this team has close links with the Forecasting Research Branch in which the 10-level atmospheric model was developed. The main task of this team is to write and develop programs to obtain various pictorial or digital outputs from the 10-level model and data banks to meet the requirements of the forecasting staff within CFO and to satisfy other national and international commitments of Bracknell as a Regional Meteorological Centre of the World Weather Watch. Another task of the section is the handling and modification of programs used to produce analysis and forecast evaluation statistics, an essential exercise when computer-produced forecasts play such a large part in the meteorological service. This section of CFO includes the small team engaged on analysis problems and more particularly on analysis by means

of orthogonal functions, the basis of the work concerned with developing four-dimensional analysis referred to earlier.

CFO remains responsible for the publication of the *Daily Weather Report* (*DWR*) with its *Overseas Supplement* and *Monthly Summary* and the *Daily Aerological Record* (*DAR*). The production of the observational material for the *DWR* and *DAR* (as opposed to the charts) is now based on output from the IBM 360/195.

In the international field the Assistant Director (Central Forecasting) and the Chief Forecasting Adviser have served as members of the Working Group on the Global Data Processing System (GDPS); in addition the Assistant Director (Central Forecasting) has continued to act as Meteorological Office co-ordinator for a pilot study group for the Integrated Global Ocean Station System (IGOSS) Bathy Pilot Project.

Services for industry, commerce and the general public

Forecasting services for industry, commerce and the general public are provided directly by the Weather Centres and a number of other forecasting offices whose primary responsibility is towards aviation, or indirectly through radio and television, the Press and the Post Office Corporation's automatic telephone weather service (ATWS). Some 40 offices in most parts of the country provide direct meteorological advice to the community, but the Office has long been conscious of the fact that, in this respect, western Wales was very poorly served. It was gratifying, therefore, to be able to arrange during the year for limited public service work to be undertaken by the meteorological office at the Royal Aircraft Establishment at Aberporth. This development was warmly welcomed by agriculturalists in western Wales who previously had to make expensive, long-distance telephone calls to obtain personal meteorological advice.

Following a two-year period of hesitation, the public demand for weather information increased sharply in 1973. Direct inquiries to all forecasting offices reached a new record of 1 745 888 exceeding by 10 per cent the 1972 total of 1 582 129 and by a considerable margin surpassing the previous record total of 1 633 478 in 1970. Table X gives a breakdown of these inquiries according to purpose. Inquiries relating to holidays, the vast majority of which are casual inquiries answered without charge, continued to occupy the dominant position in the table and, indeed, took a larger share of the total inquiries than in any previous year. Not surprisingly, the largest increases in monthly totals of inquiries were recorded in the peak holiday months of June, July and August; at 189 000 the August total was only some 15 000 short of the highest-ever monthly total recorded in February 1969, a month of exceptionally severe weather and heavy snowfall. The growth in the number of casual telephone inquiries during the summer months is a matter of some concern, since this is the time of year when most offices are operating under strength because of annual leave commitments and when a big influx of casual telephone calls may distract staff engaged on priority work.

Calls on the Post Office Corporation's automatic telephone weather service also reached a new record total of 15 501 162 as against 12 860 788 in 1972. The experience of other countries suggests that there is scope for further

appreciable growth in this service and with this object in mind a meeting was held with Post Office representatives in October to consider ways and means of making a local forecast available on the automatic telephone service on a much broader basis than at present. Again, in 1973, by local arrangement, forecasts were provided in connection with a marine information service operated in the Swansea telephone area during the summer, and for a ski report service operated in the Edinburgh telephone area during the winter months; the latter service proved very popular and attracted over 63 000 calls during the 1972–73 winter.

In the field of broadcasting the year saw a number of changes, perhaps the most interesting in the long term being the advent of commercial radio. As with BBC local radio, this promises to be a valuable outlet for local, up-to-the-minute meteorological advice and it is the intention of the Office to take the fullest possible advantage of this outlet to improve its services to the community at large. It was thus disappointing that, after very careful consideration of existing commitments and the staffing position at London Weather Centre, it could only be concluded that the requirements of the first commercial radio station to go into operation, the London Broadcasting Company, could not be met in their entirety; as a result the Company decided to employ its own 'weatherman', but was accorded certain facilities at the London Weather Centre. In the provinces approaches for a service of local forecasts were received from a number of potential commercial radio companies and discussions with these companies are continuing.

With the opening of Radio Carlisle in November, the number of BBC local radio stations supplied with routine forecasts and warnings rose to 20. Several stations expressed interest in forecast information for areas other than the local area of the station to meet demands from holiday-makers, inshore fishermen and yachtsmen; wherever possible these requirements were met.

Coincident with the introduction of hourly news bulletins on Radio 4 in July, additional scripted forecasts for the United Kingdom were provided for inclusion in each bulletin; several other minor changes were also made. This new programme of forecasts for Radio 4 overcame, to a certain extent, objections from English listeners concerning the reduction in information for Wales, Scotland and Northern Ireland which had resulted from the Radio 4 re-organization of the previous year. In Scotland, as a result of the reorganization of the 'Today in Scotland' programme, the 'live' presentations by staff of the Glasgow Weather Centre were discontinued at the beginning of the year and subsequently replaced by short scripted forecasts. Following the near-tragedy in Snowdonia a request was received from the BBC for a short forecast specifically directed to Snowdonia to be included in the early morning and weekend Welsh regional forecasts; this was agreed, but it was recognized that the scarcity of actual reports of weather from Snowdonia, particularly at night, would have an adverse effect on the accuracy and the value of these forecasts.

For a number of years London Weather Centre has provided a 'live' contribution to the Radio 4 'Farming Today' programme from Tuesday to Saturday, in which the forecaster deals with particular weather problems which may face farmers over the next 24 hours. In June, at the request of the BBC, London Weather Centre also contributed to the 'Farming Week' programme each Monday, paying particular attention to the likely weather developments over the week ahead.

Services to Radios 1, 2 and 3 continued with a few minor changes, the more important being the provision of brief actual and forecast weather information for presentation during some of the popular 'shows' on Radios 1 and 2.

The service on BBC Television was markedly improved by the introduction on 1 January of a 40-second presentation after the early-evening News Summary on BBC 2, in which the forecaster out of vision presents the forecast on weather maps which are in vision; this represents a major step forward following a long period of negotiation. On BBC 1, with the re-introduction of the lunch-time news magazine programme, 'Pebble Mill at One', in October, provision was made for an extension of the weather presentation to include answers to viewers' questions and this promises to be a popular item. At the same time it became possible to present the twice-monthly 'monthly weather survey and prospects' during this lunch-time presentation rather than, as previously, during the 'close-down' presentation. A further welcome change was the move of the Friday night presentation on 'Weekend Weather' from 'close down' to a more popular viewing spot after the Late Night News. Services to the independent television companies continued largely unchanged.

A number of broadcasts and interviews were given by members of the staff on radio and television; most of these concerned current weather. The Office provided facilities for the filming of various aspects of its work by several teams from the BBC and also from some of the independent television companies.

Services to the Press continued as in previous years. As usual, many requests were received from the national and provincial Press for special interviews and comment on a variety of topics. The international decision to locate the European Centre for Medium-range Weather Forecasting in the United Kingdom stimulated particular interest.

Demands for the specialized services provided by the Office continued at a high level. The winter service of 'warnings of certain road dangers due to weather' to local authorities and others attracted 427 registrations for the full service and 30 registrations for a limited service as against 422 and 35 registrations respectively in 1972. The services for pigeon racing were again in good demand, 1352 'line-of-flight' forecasts being issued during the racing season to 101 pigeon organizations. The demand for the 'notification of fine spells' service showed a further decline, 207 farmers and others registering for the service as against 223 in 1972.

Some two years ago a special service given the name 'Metgas' was devised at the request of the Gas Council, now the British Gas Corporation, to meet the growing requirement of the industry for more detailed weather information. Initially taken only by the Gas Council and Area Boards in the south-east, the 'Metgas' service has been steadily extended and, with the addition of the Scottish, Northern, North Eastern, North Western, Southern and South Western Gas Boards during the year, is now being taken by 10 of the 12 Area Boards. The 'Metgas' service includes, *inter alia*, six forecasts per day of temperatures at two-hourly intervals and winds at four-hourly intervals for periods of up to 24 hours, and in some cases 36 hours ahead.

The issue of short-period forecasts several times a day to the Grid Control Centres of the Central Electricity Generating Board continued. The forecasts include details of temperature, wind, weather, cloud cover and lightning risk for periods up to 12 hours ahead. A 'day-ahead' forecast, issued in the early

afternoon, forms the basis of 'demand-forecasting' for the following day, while each Friday a forecast for the following three days is issued to assist maintenance planning over the weekend.

Elsewhere on the industrial and commercial front, routine services continued to be provided to British Rail, London Transport, the North Sea oil and gas exploration and production industries and many smaller concerns.

The Weather Centres at London, Glasgow, Manchester, Newcastle and Southampton and the public service office at Watnall handled the bulk of the work in the public sector. Excluding weather maps provided for shipping at certain major ports, the total numbers of inquiries dealt with over the past three years are shown below:

	London	Glasgow	Manchester	Southampton	Newcastle	Watnall
1971 ...	303 695	91 430	107 228	79 976	82 654	62 728
1972 ...	313 024	89 770	116 914	93 532	81 889	57 483
1973 ...	309 453	109 941	131 593	96 868	94 658	62 415

Grand totals: 1971, 727 711; 1972, 752 612; 1973, 804 928.

In the London area the demand for weather information appears to have stabilized over the past few years, but elsewhere 1973 saw a further increase in demand; this was particularly so in the Glasgow area where the 1973 total represented a 22 per cent increase over 1972.

Public interest in the work of the Office continued unabated. Organized visits by parties of the general public reached an all-time record total of 104, while a further 19 visits were arranged for representatives of the Press and various broadcasting organizations. Requests for talks to be given to outside bodies were received almost daily and, while it was quite impossible to meet them all, over 150 lectures and talks were given voluntarily by members of the staff during the course of the year. There can be little doubt that the general public is becoming increasingly aware of the complexity of the work of the Office and of the wide range of its activities. Perhaps, in due course, this greater awareness will lead to a wider and more effective application of meteorological advice with undoubted benefit to the nation's economy and to the community at large.

Services for the general public (overseas)

Oil-drilling operations around the coast of Malta and marine and civil engineering inquiries continued to require special meteorological service at overseas stations. In Gibraltar, Malta and Cyprus the forecasting offices also continued to provide for the needs of the local Press, radio and television companies.

Services for marine activities

General services to shipping via BBC radio and the Post Office coastal radio stations continued as in previous years. At the request of the Scottish Inshore White Fish Producers Association Ltd, reports for Lerwick Observatory were included as routine in the Inshore Waters Forecast bulletin issued every evening on Radio 4 Scotland.

To meet a popular demand from local fishermen and yachtsmen, certain of the forecasts broadcast by Radio Teesside and Radio Blackburn were

extended to include the inshore waters Hartlepool to Whitby and Lytham to Fleetwood respectively. The special services provided by London Weather Centre to the North Sea offshore industry continued as before.

During the summer months several Meteorological Offices met an ever increasing demand from the sailing fraternity for information on actual and future weather conditions likely in coastal and inland waters, for instance, Southampton Weather Centre introduced a special service to yachtsmen in the form of a week-end sailing forecast issued every Friday afternoon. The forecast depicts the actual surface chart at 06 GMT on Friday and the forecast surface chart for 06 GMT on Saturday and includes an assessment of the likely developments over the week-end together with a detailed sailing forecast for the local area for Saturday. Although small charges have to be made for this service, it proved very popular and almost 5000 charts were distributed during the summer months to marinas, yacht clubs and individual yachtsmen.

At the request of the Royal Ocean Racing Club, special arrangements were made for the provision of a 'host-nation' forecast service during the series of Admiral's Cup races in August; charts prepared at Southampton Weather Centre were picked up by helicopter and flown to Cowes or Gosport as appropriate for distribution to competitors.

Forecasts for Royal Navy ships are supplied by Pitreavie and Plymouth/ Mount Batten offices, and Royal Air Force marine craft flights at home and abroad receive forecasts from suitably located offices. The Coastguard authorities and a number of harbour masters are other recipients of a regular forecast service, and some ships in the English Channel receive forecasts from Plymouth by ship–shore radio.

The Pitreavie office issues routine forecasts for the North Sea fishing fleets. This service covers the six months from October to March for the sea areas Viking, Forties, Fisher and Fair Isle.

Weather forecasts were supplied to the trawler fleet off Iceland until the beginning of May by a forecaster on a Support Ship. This personal service was resumed in the middle of September. From May to September, during the season of less hazardous weather, forecasts were supplied by CFO Bracknell. The forecaster on the Support Ship maintains close liaison with the British fishing fleets in the area, issuing forecasts and warnings of gales, storms and ice accretion twice daily and more frequently as and when the weather situation demands.

Ship routeing services continue to be provided for both the Atlantic and Pacific Oceans, 1973 being the first full year for the latter service. About 50 Pacific ship routeings were made during the year and about 260 ship routeings were made on the Atlantic Ocean. In general the aim of the routeing service is to provide ships with advisory routes or courses to steer, so that the time of crossing will be the least, commensurate with the avoidance of wave conditions liable to cause damage to the ship or its cargo. This aim, however, becomes somewhat modified in relation to large tankers carrying liquid cargoes when the least-time route is of more importance, because the vessels are very robust but the cost of operating them is very high. In order to predict the speed of the vessel in the wave patterns it is expected to experience, it is first necessary to know its performance in various states of sea beforehand. To obtain this information a Nautical Officer visits the ship in port before its first routed voyage if at all possible and extracts data from the ship's logs to enable him to

draw graphs of the ship's performance in relation to the wave height for various relative directions of approach between ship and waves, i.e. waves from ahead, abeam or aft. The speed is then calculated along various possible tracks in relation to the predicted wave patterns and some regard is also given to the general conditions in the outlook beyond 48 hours ahead. The main features of the general atmospheric circulation are also taken into account in arriving at the advice to be given to masters, particularly on the Pacific, where voyages usually last about three weeks. A number of other factors, such as the likelihood of fog or ice and the direction and speed of ocean currents are also taken into account. Normally the master is contacted by telephone in the U.K. port shortly before sailing and regular advice and forecasts are sent to him thereafter at least as frequently as every 48 hours, through the Post Office transmitter at Portishead (near Bristol).

The shipping forecasts broadcast four times a day by the BBC and the gale warnings prefixed 'attention all shipping' originate at CFO and are of course very well known. Lesser-known services which CFO provided for marine activities in 1973 included forecasts for the oil-drilling ship *Glomar North Sea* situated off southern Ireland for much of the year and for movements of oil rigs from one area to another. Forecasts were provided also for the cable-laying ship *Mercury* whilst she was engaged in laying a new cable between Europe and America. Also in connection with this activity, CFO provided forecasts and warnings for the rescue operations which were mounted at the end of August and in early September to recover the midget submarine which found itself unable to surface after digging a trench for the cables; fortunately although time was very critical the submarine was brought to the surface and its two-man crew saved. Amongst various forecasts for yachting, mention should be made of those provided for the Admiral's Cup races, an event which covers several days and which took longer this year owing to the calm foggy weather over the south-west approaches at the end of the Fastnet race. The capability exists for the forecasting of the movement of oil slicks, but this service was not called for during 1973.

CFO works closely with the officers of the Storm Tide Warning Service who are responsible for issuing alerts when flooding due to the effect of strong winds causing unusually high tides on the east coast of England is possible. Regular forecasts of wind and weather in certain northern coastal areas were issued to Geophysical Services International Ltd and warnings of tropical hurricanes, cyclones and typhoons were issued to Lloyd's when appropriate.

Services for civil aviation

The Meteorological Office acts as the agent of the Civil Aviation Authority in the supply of meteorological information for civil aviation within the United Kingdom.

The Principal Forecasting Office at London/Heathrow Airport is the designated European Area Forecast Centre for all flights to the U.S.A., Canada and parts of the Caribbean from European terminals. Transatlantic-flight documentation is disseminated by land-line facsimile to Dublin, Paris, Frankfurt, Rome, De Bilt and Copenhagen and also by radio-facsimile broadcast to more distant parts of the European area. Forecasts charts for routes to Africa and India are received from the other European Area Forecast Centres of Paris,

Rome and Offenbach (Germany); in May land-line replaced radio-facsimile reception from Rome and Offenbach, that from Paris already being by land-line.

The Principal Forecast Office at Heathrow also acts as the hub of the Civil Aviation Facsimile Network (CAMFAX) and by this means provides flight documentation to major civil airports throughout the United Kingdom. For flights above 5000 ft ($\approx$1500 m) forecast charts relating to *en route* weather conditions and upper winds and temperatures are issued at 6-hourly intervals as routine. These cover the two main areas of operation—(a) the whole of Europe, including the Mediterranean, and (b) the North Atlantic.

The Civil Aviation unit at CFO, Bracknell, continues to be responsible for the preparation from data processed by the IBM 360/195 computer of forecast upper-wind and temperature charts required by civil aviation. These charts are transmitted to Heathrow by facsimile. Charts depicting *en route* weather likely to affect the safety of aircraft in flight are prepared locally at Heathrow.

Meteorological services for general aviation (private pilots, flying clubs, air taxi services etc.) are provided by local civil aviation and RAF meteorological offices on request. For flights in this category below 5000 ft special flight forecasts are prepared giving information on cloud, visibility and other phenomena which may be hazardous to light aircraft, in more detail than is required for flights at much higher levels by the major airline operators. The operational trials of an answer-phone service for general aviation have continued. Forecasts for 21 areas covering England and Wales and the near Continent are provided in an abbreviated form by the Principal Forecasting Office at Heathrow and the Main Meteorological Office at Preston; they are tape-recorded at dictation speed. Pilots may receive both these forecasts by telephoning advertised numbers at Preston or West Drayton.

As part of a plan to make the most efficient use of available man-power the Main Meteorological Office at West Drayton closed in April and its forecasting commitments were transferred to the Principal Forecasting Office at Heathrow. A small unit remains at West Drayton to meet the meteorological requirements of the London Air Traffic Control Centre (LATCC) and the CAA/MET Telecommunication Centre.

BOAC has continued to operate its computerized flight-planning service for flights across the Atlantic, both westbound and eastbound. The meteorological forecast data required, comprising upper winds and temperatures at about 35 000 ft ($\approx$11 000 m), in a grid-point format, are supplied by telex to BOAC at Heathrow from the Bracknell computer twice daily for validity times 18 and 24 hours ahead. A similar service to the Apollo computer unit at Shanwick Oceanic Control at Prestwick is also provided twice daily.

The Principal Forecasting Office at Heathrow, through the Concorde Forecasting Office at Fairford, Gloucestershire, has continued to provide special forecasts for Concorde test flying.

Members of the Office were included in the U.K. delegations at the International Civil Aviation Organization (ICAO) Regional Air Navigation Meetings held at Rome (in January) and at Honolulu (September) to make arrangements to cover civil aviation needs in the period to 1978. The Rome meeting considered the needs of the African Continent and adjacent islands while the Honolulu meeting covered the Asian Continent (except in the Middle East) and the Pacific Ocean.

Services for civil aviation (overseas)

Forecasting services were provided at Gibraltar, Malta (Luqa), Wildenrath, Gütersloh, Nicosia, Masirah and Salalah to meet the needs of civil and general aviation (private pilots, flying clubs etc.) in accordance with International Civil Aviation Organization (ICAO) regulations and international agreements.

Services for the Royal Air Force

A senior officer of the Meteorological Office is located at most RAF Command Headquarters at home and overseas. This officer acts as adviser in meteorological matters to the Air Officer Commanding-in-Chief and as liaison officer between him and the Director-General of the Meteorological Office.

Forecasting services continue to be provided for the Royal Air Force at home by stations distributed largely in conformity with the RAF organization. There is a Principal Forecasting Office at Headquarters Strike Command and Main Meteorological Offices, functioning throughout the 24 hours every day, are located at various centres to control and advise subsidiary offices which are located at aerodromes and enable them to meet the various requirements of aircraft of many types operating in many different roles. At the subsidiary forecasting offices, a forecaster is on duty at times which depend on the requirements of the Royal Air Force.

Maximum use is made of the technical support which is provided by the large IBM 360/195 computer at Bracknell. At Headquarters Strike Command and 46 Group a comprehensive six-hourly programme of preparation and issue of area and route forecasts in chart form is maintained as routine to meet the majority of operational requirements. These routine issues include a forecast surface-analysis chart and a significant weather chart in addition to upper-air forecasts for standard levels. The charts are distributed by land-line facsimile to the subsidiary offices where they are duplicated for issue to aircrews at pre-flight meteorological briefings.

Mobile meteorological units are established to support RAF and Army elements participating in certain field exercises in the U.K. and overseas. Each unit has its own air-transportable sets of meteorological and communication equipment for use at locations which are removed from permanent meteorological offices. The facilities include radio-teleprinters, radio-facsimile recording equipment and special apparatus for receiving satellite cloud-pictures. Forecasters in the mobile units hold commissions in class C.C. of the Royal Air Force Reserve of Officers. Special techniques have been evolved for dealing with the forecasting problems which arise in this type of operation.

Meteorological officers continue to give regular courses of meteorological instruction at a number of schools in Training Command and to some Operational Conversion Units. The RAF team which has been formed to prepare a programmed instruction training package on meteorology for use at RAF schools has made steady progress during the year and a meteorological officer has been attached to the team to act as adviser.

The installation of equipment for the measurement of runway visual range (RVR) is now either completed or approaching completion on many RAF airfields. The Meteorological Office provides technical advice concerning the RVR system and calibrates the lights after they have been installed. Each airfield system is also checked and recalibrated every six months.

A military VOLMET broadcast of plain-language weather reports for major RAF aerodromes was continued. This broadcast is provided mainly to meet the needs of transport aircraft returning from overseas to bases in the United Kingdom.

New procedures for the provision of meteorological services for Royal Flights were introduced. These include an in-flight service for helicopters flying over England and Wales.

With a view to effecting an economy in manpower, a study has been started of a reorganization of the meteorological service for RAF airfields in the east of England. It has been decided that the Main Meteorological Office which is currently located at Manby shall be disbanded and its responsibilities distributed between other major offices.

The pattern of meteorological services for the RAF overseas also conforms closely with the organization of the two major RAF overseas Commands. In the Federal Republic of Germany there is a Main Meteorological Office at Rheindhalen which supports the subsidiary forecasting offices at the RAF airfields and also the Allied Meteorological Office at Maastricht in Holland. In Cyprus the Main Meteorological Office at Episkopi provides technical support to the subsidiary offices in Cyprus itself as well as to those in Muscat and Oman. There are similar Main Meteorological Offices at Gibraltar, Malta and Gan and these provide forecasts for the western Mediterranean, the central Mediterranean and much of the Indian Ocean areas, respectively.

The Central Forecasting Office at Bracknell provides strong technical support for Europe, the Mediterranean and the Near East, chiefly by broadcasts of teleprinter data and facsimile charts. These are received at the more important overseas stations. However, to augment this support British overseas stations also have to make use of locally collected data. Accordingly six stations have been established at bases overseas to receive cloud pictures by automatic picture transmission (APT) from the U.S. weather satellites. These are supported by powerful weather radars in Malta, Cyprus and Gan, and by a network of thunderstorm location (SFLOC) stations in the Mediterranean. This auxiliary information continues to be of the utmost importance to the overseas stations.

Services for the Army and Establishments of the Procurement Executive, Ministry of Defence

The year has shown a marked increase in the work undertaken for the Army and MOD(PE) units. Whereas some of the additional work is undoubtedly directly due to the scientific and technological developments taking place within these organizations, much appears to be due to the growing awareness, within the Army and associated branches, that meteorological support is becoming an essential part of their planning and operational roles.

During the year the second forecasting office for Army Aviation was opened, at Middle Wallop, and arrangements to open a third such unit at Detmold, Germany, in Spring 1974 are now approaching completion. A meteorological officer is stationed with the Headquarters No. 1 (BR) Corps, Bielefeld, Germany, to provide professional advice to the General Officer Commanding and his staff. The officer, suitably supported by additional staff and communications, takes full part in exercises in the field from time to time.

Trials of the Army Meteorological System (AMETS), which is an automated system for the measurement and processing of upper-air data for ballistic purposes, have been completed during the year. Satisfactory accuracy of the meteorological parameters measured has been achieved and the first production model of the system has been accepted by the Army. Further development is contemplated by the Operational Instrumentation Branch in connection with proposed foreign sales of the AMETS equipment.

Offices were maintained at MOD(PE) establishments at Shoeburyness, Larkhill, Eskmeals, Aberporth and Pendine. These offices cover all the meteorological aspects of the Proof Experimental and Trials work of the establishments. Noise (acoustic) assessments are made at Shoeburyness, Eskmeals and Larkhill. The office at Shoeburyness also caters for the meteorological requirements of the Atomic Weapons Research Establishment, Foulness.

Members of the staff of the Office were attached to the Army practice camps at Sennybridge and Otterburn to provide meteorological information for ballistic purposes during exercises on several occasions through the year.

Because of the proposal to build a new airport and dock complex on Maplin Sands, planning for the immediate move of some units and the future move of other units prior to eventual closure of Shoeburyness has continued throughout the year. Arrangements have been made for a new forecast office to be opened at Spadeadam, near Carlisle, in May/June 1974, and long-term planning for the provision of meteorological facilities at other sites continues.

Liaison with the Navy Department

The need for the co-ordination of plans to meet the meteorological requirements of defence forces at home and overseas has continued to require close co-operation with the Directorate of Meteorology and Oceanographic Services (Naval).

International defence services

The co-ordination of the international meteorological support required by the military forces, and of the study of any associated meteorological problems, is undertaken by the various meteorological planning committees of the international defence organizations NATO, CENTO and SEATO, to which the United Kingdom belongs. The Meteorological Office participates actively in the work of the various meteorological committees.

Services to the Home Office

The meteorological requirements of the Warning and Monitoring Branch of the Home Office have been kept under review and detailed plans for meeting these requirements as effectively as possible in an emergency are maintained and tested in exercises. Miscellaneous lectures were given to groups of Home Office Sector Scientists, Chief Warning Officers and members of the Royal Observer Corps who are equipped and trained to make simple meteorological observations in times of emergency.

Services for nuclear establishments

To meet requirements for meteorological information under the arrangements to deal with the accidental release of radioactive or toxic material, certain Main Meteorological Offices provide information to nuclear establishments. These arrangements are tested without notice twice a year with the

establishments concerned, which are operated by the United Kingdom Atomic Energy Authority, the Central Electricity Generating Board and the South of Scotland Electricity Board.

Climatological Services

The main function of the Branch is to provide information and advice about climate. The foundation of the service is a network of about 650 observing stations of various types in the United Kingdom. About 70 of these are manned by Meteorological Office staff who make frequent observations, in some cases at every hour of the day and night, and about 60 are auxiliary stations where observations are made several times each day (by lighthouse keepers, coast-guards etc.). The remainder are maintained by voluntary observers and the Office takes this opportunity to thank them for their excellent co-operation. The Branch is responsible for the inspection of the network and for the collection, quality control, publication and preservation of surface and upper-air observations made at stations in the United Kingdom. The surface observations are published in the *Monthly Weather Report* (*MWR*) and its *Annual Summary* and in some non-routine climatological publications. Computer quality control has been extended to cover the data received from all types of climatological stations and work continues on refining the methods employed but some measure of human control still has to be applied. Work on a computer system of providing printer's copy for the whole of the *MWR* has reached an advanced stage. In collaboration with the Operational Instrumentation Branch, work has continued on the development of a digital anemograph logger which will eliminate the laborious hand analysis of wind records.

Developments in the application of climatology continued but not all demands could be met with the staff available. In order that work on projects of particular interest to it may proceed, the Department of the Environment has agreed to fund two scientific posts in the Climatological Services Branch.

The general growth over the years in the number of climatological inquiries has continued: the number in 1973 exceeded that in 1972 by about 11 per cent (Table XIII). As usual the inquiries covered a wide range and included many legal questions concerning past weather, requests for climatological data in connection with the design requirements and sitings of buildings and structures and for climatological data relevant to the sales of commercial products and storage of materials. For example, in connection with a projected suspension bridge over the River Humber, estimates were provided of the frequency of high winds, fog and low cloud which might interfere with its construction and of the frequency of cross-winds which might affect traffic flow when the bridge is in use. Other interesting inquiries were for the distribution of strong winds as a factor for consideration in the selection of sites for inshore and offshore terminals for tankers bringing oil from wells in the North Sea and off northern Scotland; the frequency of days with low temperatures in connection with the construction of a dam about 600 metres above mean sea level in Wales; and the occurrence of unusually high temperatures for an investigation into distortion of railway tracks. Advice was given on the selection and siting of meteorological instruments along possible high-level sections of the proposed

Manchester–Sheffield motorway. The data collected are being analysed to assist in the final selection of the route and to establish design criteria for the wind-loading of viaducts.

While most requests are for information relating to the United Kingdom, the Office must also be prepared to answer inquiries about the climate of any other country. Data to meet this requirement are usually collected by means of an international exchange of processed material. Examples of such inquiries answered during the year are: for extreme wind speeds likely to affect a power line to be built in Iran over terrain reaching 2700 metres above mean sea level; for information on synoptic systems associated with rainfall in south-west Saudi Arabia in connection with a mathematical model for water run-off in the area; and for temperature and humidity data at cities in western Europe in connection with the storage and deterioration of photographic materials.

The Office continued to collaborate with government or government-associated agencies such as the Building Research Station, the Transport and Road Research Laboratory and the British Standards Institution (BSI). A senior officer served on a BSI Committee which was reconvened late in the year to consider the revision of the codes of practice dealing with loading of buildings. The Office's contribution has been chiefly concerned with the effects of wind, snow and ice. In this connection, the analysis of extreme winds over the United Kingdom was brought up to date and summarized in a *Climatological Memorandum.*

Climatological services for Scotland and Northern Ireland are provided by offices in Edinburgh and Belfast respectively. The Superintendent of the Edinburgh Office served on a working party of the Scottish Development Department dealing with storm sewage and he also continued to serve as an Adviser to the Clean Air Council for Scotland. Special maps were prepared for the Scottish Development Department showing rainfall deficiencies over Scotland during the very dry spell which started in July 1972 and continued on the eastern side throughout most of 1973. In spite of the continuing unrest in Northern Ireland, the number of inquiries dealt with by the Belfast Office increased by nearly 20 per cent on 1972 and the Senior Meteorological Officer and his staff are to be commended on the way they have maintained their services.

The marine climatological section completed the 1963 and 1966 volumes of the annual publication *Marine climatological summaries for the Atlantic Ocean east of* 50°*W and north of* 20°*N*, which, by international agreement, is published by the Office. The volumes for 1963 to 1966 inclusive have now been published and the preparation of the volume for 1967 is well advanced.

Monthly charts showing the distribution of sea-ice at the end of each month were issued as usual. Work continued on the task of checking ocean current data and preparing them for computer quality control. The ocean current and, where applicable, the sea-ice sections were revised for seven volumes of the Admiralty *Pilots*. The revision of the *Pilot for Antarctica*, which necessitated many months' work, was of particular interest and importance since it incorporated many new data mostly from satellite sources concerning the distribution of sea-ice in the area. Chapters 17 and 18 (on sea-ice) were revised for the publication *Meteorology for Mariners*. Routine articles on sea-ice and items for the 'Marine Observers' Log' were provided for the *Marine Observer*. A major investigation was initiated into the preparation of new normals and frequency

distributions of sea-ice in the Arctic. The data for the last eight years have been extracted from the Monthly Ice Charts which are based on conventional data and data from satellite observations.

Many inquiries relating to marine climatology, ocean currents and sea-ice were dealt with. Information provided included a catalogue of gales in the southern North Sea prepared for the Post Office in connection with damage to cables lying on the sea bed, statistics on wind speeds in the English Channel for the design of a radar mast for ship surveillance and wind and wave data in the southern North Sea for a feasibility study into the construction of artificial sea islands for waste disposal and industrial development.

The marine climatologist continued as a member of the Working Group on Marine Climatology of the Commission for Marine Meteorology (CMM) of The World Meteorological Organization (WMO) and as CMM rapporteur on the meteorological aspects of icing on the superstructure of ships and installations at sea. He represented WMO at two international meetings held in London of the Inter-governmental Maritime Consultative Organization Sub-committee on Safety of Fishing Vessels. As Office representative he attended six meetings of the Offshore Installations Technical Advisory Committee of the Department of Trade and Industry and two meetings of the Working Group on Climatology of the Natural Environment Research Council. Work continued on relationships between wave heights and wind speeds in U.K. coastal waters and a joint paper on the subject with a member of the staff of the Institute of Oceanographic Sciences was completed.

Hydrometeorology

The routine hydrometeorological work of the Office covers the regular collection, scrutiny, processing and preservation of rainfall data from some 6900 stations and evaporation data from some 60 stations in the United Kingdom and Northern Ireland. The Edinburgh Office administers and inspects stations in Scotland, handles their data and deals with local inquiries whilst the Belfast office has similar responsibilities for Northern Ireland. Regular inspections of the stations are made to ensure the maintenance of required standards of site, instrumentation and observational procedures and 697 stations were visited during the year. Most of the data are collected from voluntary co-operating stations maintained by river authorities, local authorities, water supply undertakings, and last but not least by private individuals.

To facilitate collection of data from larger bodies such as river authorities a Datel 200 data link terminal has been installed at Bracknell. Currently only the Sussex River Authority are using the facility for passing data to the Office but it is expected that other authorities will take advantage of it in the near future.

New programs for the quality control of rainfall data came into operational use during the year. The large capacity of the IBM 360/195 computer enables the daily rainfall observations from approximately 6000 stations in the United Kingdom to be quality-controlled in one operational run each month. The monthly totals of rainfall for the 6000 daily stations and for an additional 1000 monthly stations are similarly quality-controlled by use of a separate program. Rainfall data are published in the *Monthly Weather Report* and in *British Rainfall*, and from time to time in non-routine publications and branch memoranda. *British Rainfall* for 1966 was issued, while the texts for *British Rainfall* for 1969

and the second five-year supplement to *British Rainfall*, namely that for 1966–70, are nearing completion and good progress has also been made on the 1970 volume of *British Rainfall*. The scrutiny of evaporation data being collected is continuing and tests of programs for routine processing and quality control, similar to those for rainfall data, are being run.

A preliminary map of average annual rainfall over the United Kingdom for the period 1941–70 has been produced. This map is based on records from more than 6000 rainfall stations for the 1961–70 period and on records from 600 rainfall stations for the 1941–70 period. Work on the final version of the average annual rainfall map is nearing completion.

Two important developments regarding close time-scale detail from rain recorders are progressing. The operational assessment of the magnetic-tape rain recorders has required a painstaking effort; these magnetic-tape recorders provide ready translation of the detailed data into computer media for analysis and archiving. The second project of transferring data obtained by conventional rain recorders (traces on paper) to digital information on magnetic tape, using the precision encoding and pattern recognition (PEPR) equipment at the Nuclear Physics Laboratory, Oxford, is continuing with gathering momentum. This PEPR project is expected to deal with some two million daily charts in about three years and thus provide a large and detailed archive of accumulated old data which were not previously adequately analysed manually because of the great effort which would have been involved. Hydrometeorological inquiries from the public, from commercial and research organizations and from many other bodies and covering a very wide field have been answered, the work load being at much the same level as last year. Use has already been made of some results obtained by the Flood Studies team in answering inquiries relating to storm-water drainage. (The Flood Studies investigation is described later.)

Estimates of daily areal rainfall and monthly areal potential evaporation have been prepared for the Thames Conservancy. These estimates covered two years for Thames tributary catchments overlying 25 specified aquifer units and long runs of years for areas in the Cotswolds, Berkshire and Surrey. For the Water Resources Board a year's assessments of areal rainfall were made for 31 areas over England and Wales. Monthly areal rainfall and both potential and actual evaporation were estimated for three chalk areas south of Cambridge. A report on the effect of weather on ground water was provided for the 1968–70 *Groundwater Year Book*. Computer programs have been written to produce monthly areal rainfall estimates for the Surface Water Survey. The return periods of some outstanding one-day rainfalls over the Derwent and Cocker catchments were estimated to assist development of the Cumberland River Authority's flood warning scheme. Monthly estimates of evaporative water loss from Lough Neagh have been supplied to the Freshwater Biological Investigation Unit (Northern Ireland) for the years 1970–73.

Programming developments have made it possible to make special issues of the present form of the bulletin *Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain* at short notice, as necessitated by important weather changes. The design of the new advisory system was documented and a good deal of the necessary programming and background field preparation has been completed.

As part of a study of long-period rainfall and evaporation in the London area an analysis of a 274-year rainfall series was published and another paper

described the assembly and treatment of a parallel series of estimates and measurements of evaporation. Further progress has been made in developing the quality control of evaporimeter data.

The deficiency of the rainfall of England and Wales, for much of the period from July 1972 onwards, was kept under continuous review and special reports were supplied to the Cabinet Office, the Department of the Environment, and the Water Resources Board.

The extreme accumulated deficiency of rainfall over Britain from July 1972 and for much of 1973 prompted a special investigation into droughts. A preliminary report has been written, and this distinguishes between 'meteorological', 'hydrological' and 'agricultural' drought. Each of these terms is parameterized in terms of the rainfall, evaporation, potential evaporation etc. Hydrological drought concerns water shortages in reservoirs and aquifers, whereas agricultural drought concerns the soil moisture stress. The project uses data over the period 1911–70 for its main investigations, but data available for Kew and England and Wales back to 1731 have been analysed in order that any vagaries associated with the period 1911–70 may be placed in perspective. Values obtained by using data from various areas in England and Wales are being analysed, and the results will be used to point the way to future research.

The comprehensive areal rainfall program (CARP) has been used to provide isohyetal analyses for several rainfall occasions. The output is on 35-mm film from the Calcomp 1670 unit which is on-line to the IBM 360/195 computer. Another program employs the Calcomp to plot, on any scale of map, the rainfall totals for a specified number of days at each of the 7000 rainfall stations. If the scale of map is such that a rainfall total cannot be plotted in its correct position then this total is printed, with its National Grid reference, in a special table. The programs referred to above are frequently employed to output rainfall data for various investigations and inquiries.

A summary of the main results to be expected from the Meteorological Office Flood Studies investigations was given in the *Annual Report* for 1972. The Flood Studies team included all of these in a comprehensive *Draft Report* which was produced in May 1973. The *Draft Report*, 145 pages plus maps, was sent to members of the Flood Studies Steering Committee and to other interested parties for their criticism and for their ideas for possible improvements. Many useful comments were received and these were incorporated into a final version of the Report which was favourably received by the Steering Committee in December 1973. This important Report is to be published as Volume 2 of the *U.K. Flood Studies Report*, the Institute of Hydrology being responsible for other volumes.

The Dee Weather Radar Project continues to make steady progress. This is an important joint study by the Office, the Water Resources Board, the Dee and Clwyd River Authority and Plessey Radar Limited to investigate the accuracy of precipitation measurements made with weather radar as the prime sensor. During the year the assessment using the Type 43S radar was completed. Over sub-catchments of area typically 60 km^2 within the 1000 km^2 of the Dee the radar estimates were generally between 10 and 25 per cent of those based on a network of 60 recording gauges, provided that the radar system was calibrated against a single gauge measurement. Part of this difference is attributed to errors in the gauge estimates of areal rainfall. Accuracy can be improved by

the use of additional calibration gauges distributed over the area. The potential superiority of the radar system over that of rain-gauges is greatest in showers, when a rain-gauge density of about 1 gauge per 30 km^2 is required to obtain comparable accuracy in rainfall measurements over a sub-catchment. In widespread rainfall the equivalent density is about 1 gauge per 100 km^2 provided that the radar beam does not intersect the level at which solid precipitation (e.g. snow) begins to melt as it falls through the air. Errors in the radar estimates are larger when the radar beam intersects the melting layer and empirical corrections have been devised which reduce the average difference between radar and gauge estimates to between 30 and 40 per cent. One means by which the effect of the melting layer can be reduced further is to lessen the number of occasions on which the beam intersects the layer. This can be done by reducing the radar beam width and in the autumn Plessey Radar Limited started work to modify the radar beam to a width of 1° instead of the initial 2°. This was accomplished by changing the operating wavelength from 10 cm (S-band) to 5·6 cm (C-band). It is expected that this change will also reduce the extent of the echo received from the surrounding topography and enable accurate measurements of rain to be made beyond the current range limit of 50 km. As in the previous year a network of schoolchildren observers was established over parts of the Dee and Clwyd catchments to measure snow depths so that the accuracy of radar measurements of snowfall could be assessed. However, progress in this study was minimal in 1973 because of the lack of snow. During the year the Dee Weather Radar Project Operations Systems Group, chaired by the Water Resources Board, and with members of the Office, Water Resources Board, Greater London Council, and Plessey Radar Limited, completed their report entitled 'The use of a radar network for the measurement and quantitative forecasting of precipitation'. This was printed by Her Majesty's Stationery Office for the Water Resources Board in December. A Colloquium on 'The quantitative measurement of areal rainfall by radar', jointly sponsored by the Meteorological Office and the Water Resources Board, and chaired by Sir Norman Rowntree, lately Director, Water Resources Board, was held at the Meteorological Office College, Shinfield Park, near Reading, on 13 December 1973.

The team of seven, led by the Principal Scientific Officer attached to the Institute of Hydrology, has obtained 54 more days of data on the energy budgets of an extensive forested area near Thetford, Norfolk. Besides providing greater understanding of the physical processes involved in the evaporation from a forested area, the measurements of the energy budget and of the related variables allow comparisons between the micrometeorology of an aerodynamically very rough surface and that of smoother vegetated surfaces such as grass, which have been the subject of previous extensive study. For eight days in the spring, eddy correlation measurements of the fluxes above the forest were made by a team from the Meteorological Research Unit at the Chemical Defence Establishment at Porton Down, at the same time as the energy budgets were measured. These data as well as all those from the total of 185 days are being analysed by use of the Institute of Hydrology's computers, to give firstly the hydrologically important results and secondly the meteorologically interesting results. It has been found that on average only about 40 per cent of the net radiation is used for evaporation of transpired water but, when the surfaces of the forest leaves are wet, the energy involved in the evaporation of intercepted

precipitation often exceeds the net radiation during the cloudy periods following precipitation.

The Office has continued its contribution to international hydrometeorology through co-operation with the World Meteorological Organization and UNESCO. The Office is represented on the British National Committee of the International Hydrological Decade.

Services for Agriculture

The pattern of services for agriculture is showing a slow but steady development. During the year a senior post was created for liaison with the West Midlands Region of the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF). In order to make more efficient use of supporting staff, this officer is located at the South Western Regional Office of ADAS at Bristol and commutes once a week to hold a weekly 'surgery' for the other ADAS specialists at the West Midlands Regional Office at Wolverhampton. A similar 'surgery' exists at Leeds, necessitated by the dispersal of the Meteorological Office staff and other Regional staff from the Yorks. and Lancs. Regional Office at Leeds to overflow accommodation at Harrogate.

A significant feature recently has been the increasing involvement of Regional Liaison Officers with the work of the Regional Technical Groups set up by ADAS to monitor the research and development aspects. The important change which has been happening in the transition from the old National Agricultural Advisory Service (NAAS) to the new ADAS is the greater emphasis on research and development and the evidence is that the impact of this change is still being felt.

A more effective method of disseminating agrometeorological data is being tried at Harrogate where soil moisture information is being made available to farmers in the automatic telephone answering services installed at Pontefract and Beverley for ADAS. Technical support to outstation staff is being strengthened by the increasing availability of primary and derived data made possible by the data banks supported by the IBM 360/195 computer.

Discussions have recently taken place with Headquarters of ADAS on the use of agroclimatologically homogeneous areas rather than administrative counties as units for data-handling. This it is hoped will lead both to a greater degree of continuity in relationships and to the use of areal averages for agroclimatic variables.

Many investigations of the influence of weather on crops were carried out. Some effort has been exerted in devising, operating and evaluating methods for predicting the optimum time for spraying against barley mildew. Considerable attention has been paid to methods of predicting the yield of barley, grain and silage, maize, oil-seed rape, and other cereals. Work was done on the weather factors which affect the quality of hops. Studies in plant protection included wind and temperature frequency analyses for glasshouse heating design, improved methods of frost surveying, the amelioration of the climate around black currants by oil heaters and measurements of illumination under glass and various other plastic materials. The work of the WMO rapporteur on mulches is now nearing completion.

The estimation of soil moisture balances has progressed and deficits under grass, sugar beet, cereals, potatoes and black currants have been estimated. The

date when drains begin to run in the autumn is now being used to evaluate the estimation of return-to-capacity dates based on the soil moisture balance. Irrigation needs within glasshouses have been studied. A frequency analysis of dry spells of one to five days duration has been made to determine days suitable for hay making or for gathering wilted silage.

Co-operation with the Soil Survey of England and Wales and soil scientists of ADAS continued. The detailed climatic reports for Ashford and Deal were published and similar reports for Sittingbourne, Kent and Great Bentley, Essex were prepared, as were the more general reports for Berkshire, Buckinghamshire and Kent.

Considerable progress has also been made in determining the role of weather factors in animal husbandry, particularly in the effects of climate and housing on production losses due to cold stress of young beef cattle. The effect of high mean day-time temperature was shown to be a most significant factor in the deaths of pigs in transit. Soil temperatures have been used for predicting the hatch of nematodes which cause parasitic gastro-enteritis. Other work in this field was concerned with cow fertility, cattle respiratory diseases, spring bloat of cattle and the relationships between exposure to heavy rainstorms and the loss of wool quality.

Although meteorological support was provided for the foot-and-mouth disease organization set up late the previous year when pigs at Stafford showed all the clinical signs of the disease, the support was withdrawn early in the year when the disease was diagnosed as the then practically unknown swine vesicular disease. It had rapidly become evident that airborne spread and hence meteorological dependence played no part in the spread of this disease. The call-out has served as a useful exercise to test the efficiency of the Office in providing meteorological support to epidemiological teams at short notice.

Lectures were given to various agricultural bodies, colleges and associations. Published papers numbered 8 during the year and 75 *Agricultural Memoranda* were issued. Close contacts have been maintained with universities undertaking research in agriculture and allied subjects, and with the research stations of the Ministry of Agriculture, Fisheries and Food, the Agricultural Research Council and similar bodies. There were also many individual inquiries from farmers, research students and others.

Observational Requirements and Practices

The Branch, of which the Marine Division under the Marine Superintendent is a part, is responsible for organizing the provision and maintaining the quality of regular meteorological observations over land, sea, and in the upper air in sufficient numbers and with a distribution in space and time appropriate to meet operational requirements. It has started work on a project to extend the U.K. network of auxiliary observing stations eastwards with the co-operation of those Companies operating fixed oil platforms in the North Sea. It specifies how meteorological instruments shall be exposed, and details the observational techniques to be employed. Field trials are organized of new or modified instruments or observing systems to determine their suitability for operational work, and their effect on the accuracy and comparability of the basic observational data.

Observational practices

An assessment of the field performance of the first of a set of nine automatic observing systems to be installed for evaluation at observing stations started in November.

A detailed study has been made of the performance in operational service of distant-reading electrical resistance thermometers. This system enables representative readings of air temperature to be obtained from screened thermometers even when an open site for the screen cannot be found near the observing office. From data obtained over the last three years it appears that the stability of the instrument is good, and that precautionary comparisons with traditional mercury-in-glass thermometers can be considerably reduced in frequency.

From time to time advice has been given upon radiosonde observational practices suitable for the special circumstances of the international GARP Atlantic Tropical Experiment (GATE) to be carried out in 1974.

Observatories

The Observatories at Kew and Lerwick, and the meteorological section at Eskdalemuir, have continued to provide facilities for testing new instruments and techniques as well as being important stations in the observing network. A major change however, has been the move, foreshadowed in the 1972 *Annual Report*, of the work of the Regional Radiation Centre and the routine calibration of radiation instruments from Kew to Beaufort Park, near Bracknell. The latter work will now become the responsibility of the Operational Instrumentation Branch, but the calibration of the working standard instruments, against which the routine instruments are compared, will still be one of the main functions of the Regional Radiation Centre. This move, only completed during the last months of the year, will enable the staff engaged on radiation work to share, to their advantage, the excellent technological facilities and expertise available at Beaufort Park and the main Headquarters. Kew Observatory will continue to be part of the Meteorological Office; the present programme of meteorological measurements will be largely unchanged but there must inevitably be some reduction in the scope of the instrumental trials work in the future.

The measurement of temperature and humidity has again been an important part of the experimental programme of the Observatories. The evaluation of the performance of the dewcel, an instrument for measuring dew-point, at all three Observatories was completed, and the instrument is now in routine use. It is particulary useful when the wet-bulb temperature is below 0°C.

At Kew an investigation into wet-bulb temperatures with different types of thermometers (both mercury-in-glass and electrical resistance) and different wick lengths has shown that there are small but significant differences; these field measurements have been confirmed and extended by laboratory investigations by staff of the Operational Instrumentation Branch.

The work at Kew on the comparison of temperatures as recorded by the aspirated psychrometer, by thermometers in a large thermometer screen and by the thermometer in the Kew North Wall screen has continued and the analysis has been elaborated. The main object in determining the relationships between these measurements is to enable in the future, when the use of the North Wall screen thermograph has been discontinued, reliable estimates to

be made of what the North Wall screen temperature would have been. In this way the long-period record from this instrument (it has been in use for over 100 years) can still be used for climatological purposes.

The comparison between the recording gravimetric rain-gauge and the standard rain-gauge is showing some interesting minor features but the main results are much as expected. A full analysis must however await more data.

Lerwick has continued to act as a WMO Regional Sampling Station and the staff have assisted in the establishment and operation of a second chemical sampling station at a remote site, some 35 miles from the Observatory. The purpose of the second set of measurements is to assess whether the Observatory is affected by any local sources of pollution now that there is increasing commercial activity in the nearby town associated with the provision of support facilities in the Shetlands, following the North Sea oil discoveries. The examination of the solar-radiation records for Lerwick and other relatively pollution-free stations to assess the long-term changes has been hindered by the work necessary to change the radiation records into a form suitable for use with the new computer, but this is now completed and the examination is being resumed.

At Kew Observatory a major programme of renovation and redecoration has been in progress throughout the year. This has been supervised by the Historical Buildings Section of the Department of the Environment and will result in this interesting old building being put into a good state once again.

Thunderstorm location and surveillance

The network of Cathode Ray Direction Finding (CRDF) stations for the detection of thunderstorms continued to function throughout the year. The four U.K. stations operated for a period of 10 minutes at 22 of the hours in each day, and fixed the positions of thunderstorm areas occurring in a region extending some 800 km from Bracknell. In addition, these four stations combined with three in the Mediterranean area to form a network providing location and surveillance (again over 10-minute periods) at 16 consecutive hourly intervals each day covering an area with a radius of about 2500 km centred near the Gulf of Genoa.

The overall system reports the presence of about 10 times as many thunderstorms as does the network of human observers distributed over Europe. From statistical considerations it is thought that the number of thunderstorm areas undetected by the CRDF network is small, perhaps less than 2 per cent.

Surface observations

In the U.K. 77 surface observing stations report in international code every hour of the day (24 hours) throughout the year; a further 50 stations report every 3 hours. In addition, 141 stations report at various times each day of the year. Of this total of 268 stations, 91 are manned by full-time staff of the Meteorological Office, 72 by coastguards and lighthouse keepers, and 70 by staff of other official and public bodies. The remaining 35 stations are maintained by private individuals, all enthusiastic meteorologists, who play a vital part in maintaining the reporting network.

The auxiliary stations manned by coastguards, from which, because of a pay dispute, no reports had been available since October 1972, rejoined the reporting network in March. The resumption of these reports restored what had

been a serious deficiency in the depleted network and the cause of considerable difficulties to forecasters.

Reports in plain language are received from 25 town offices of the Automobile Association and the Royal Automobile Club, from 20 Police or Fire Service Stations and from 53 road maintenance depots located along motorways. It is intended that the number of motorway maintenance depots making these reports will be increased as the motorway network is extended.

Upper-air observations

The normal programme of upper-air observations was continued at the eight stations in the U.K., on four ocean weather ships and at five stations overseas. Radiosonde observations made by Meteorological Office staff aboard two merchant ships were discontinued late in the year, mainly because international participation in this project had not materialized to the extent hoped for.

Meteorological Office Type 4 wind-finding radars became operational at Stornoway during March and at Gibraltar during November. This completes the programme of installations for the 13 land stations and as a result wind data can now be obtained to a greater altitude over the whole of the observing network.

Advice and assistance on radiosonde matters continued to be given to other branches of the Office as well as to outside bodies. In particular close liaison was maintained with the branch responsible for the establishment of upper-air stations in support of the U.K. contribution to World Weather Watch.

Performance of the cheaper high-altitude balloons first brought into use last year improved considerably. Performance of normal balloons remained about the same as in 1972 and is thought to be approaching the practical limit for this type.

Runway visual range

Routine check calibrations of the human observer system used to assess runway visual range have been carried out, at six-monthly intervals, at some 34 civil airports in the U.K. and at 25 RAF stations, including two in West Germany and one in Cyprus. The number of RAF stations fitted with this system continues to increase and will probably reach about 40 later next year. However, automatic instrumented systems for measuring runway visual range are now in operation at four major civil airports (London/Heathrow, London/Gatwick, Manchester and Glasgow); at London/Heathrow the human observer system has been abandoned but it is still being maintained in calibration at the other three airports for the time being.

Co-operative projects

In furtherance of the tasks of a Working Group established by the WMO Commission for Instruments and Methods of Observation (CIMO) an international comparison was mounted at Beaufort Park in May 1973, using the temperature reference sonde of Finland and the Meteorological Office Mk 3 radiosonde. As in an earlier comparison during September 1972, the U.K. team comprised staff from several branches. It was found that the temperature sensor of the Finnish sonde is sensitive to the effect of gravity. Additionally, ice can accrete more readily upon it than upon the much thinner temperature sensors of the Japanese reference radiosonde and our own Mk 3 radiosonde.

Laboratory work concerned with the effect of solar radiation upon temperature sensors was also carried out. A limited number of comparison flights were made. The mean temperature differences between the Mk 3 sonde and the temperature reference sonde of Finland for the two night flights completed is given in Figure 2. The result is similar to that of the comparison between the Mk 3 sonde and that of Japan made last year (*Annual Report* 1972, Figure 2, p. 34). It is evident that our new design of sonde is capable of giving temperature data of reference quality.

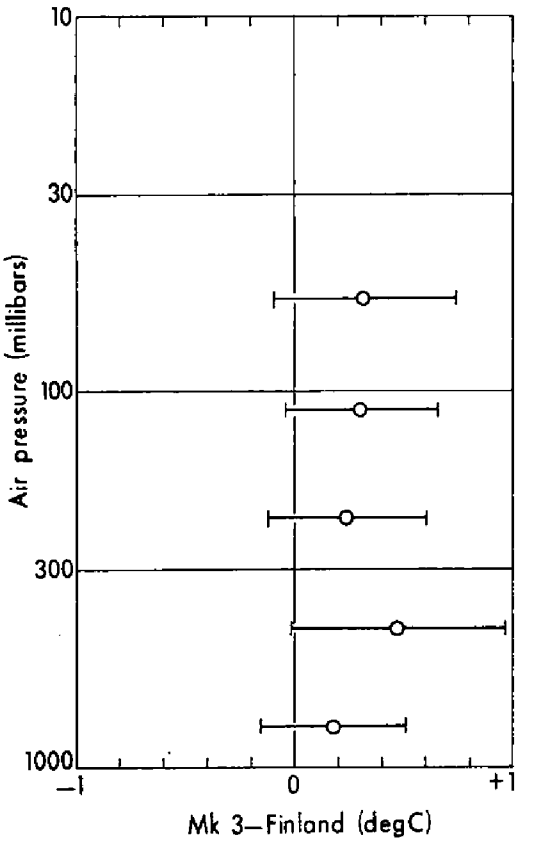


FIGURE 2—MOST-PROBABLE ESTIMATE OF THE DIFFERENCE BETWEEN TEMPERATURES MEASURED BY THE MK 3 RADIOSONDE AND BY THE TEMPERATURE REFERENCE SONDE OF FINLAND

The limits corresponding with plus and minus one standard deviation are indicated by vertical bars.

The information gained from both comparisons was presented as a comprehensive Report by the Working Group Chairman (an officer of this branch) at a meeting of the Commission at Helsinki in August. The Commission expressed its appreciation and recommended that the Report be published by the WMO.

Marine Division

The U.K. voluntary observing fleet has been maintained at just over 500 selected ships throughout the year, the number of recruitments almost balancing the considerable wastage due to ships being sold or broken up. Whilst on paper the numerical strength of the fleet has not grown, observations received have nevertheless increased since the larger container and bulk carrier type vessels spend more time at sea than their predecessors, and are therefore able to make

a greater contribution of observations. In spite of retirements and consequent changes in personnel, the Port Meteorological Officers have continued diligently their recruitment and general liaison work between the Meteorological Office and shipping interests, to their mutual benefit, bearing in mind that apart from the special-purpose ocean weather ships, meteorological work at sea in British merchant ships has always been carried out on a voluntary basis. In recognition and appreciation of this contribution to international meteorology, the customary practice has been continued of awarding books to the Masters, principal observing officers and senior radio officers of the 100 ships which have sent in during the year the most carefully kept meteorological log-books. Similar awards were made to Masters and officers of vessels on the short sea trades for their contribution in making sea temperature observations and to trawler skippers and radio officers who had the best records in making and sending non-instrumental observations from the fishing regions. Additionally, barographs were again presented to shipmasters whose observations over many years have consistently achieved high standards of excellence.

The policy of installing distant-reading marine meteorological instruments has continued and several newly built ships have been fitted with this equipment, which helps to lighten the tasks of observing officers. Shipowners approached in this connection have all proved very co-operative, in some cases the initiative coming from the shipowners themselves, a situation which favourably reflects the relations between the Office and the shipping industry through the medium of the Port Meteorological Officers.

Acknowledgement should once again be made of the valuable service rendered by many Commonwealth and foreign Port Meteorological Officers for their services in replacement of defective instruments in U.K. selected ships on protracted voyages, and recovery of instruments from British vessels which have been sold to foreign interests.

During the year, the British Weather Ships have completed 26 years of service in the North Atlantic. The present four ships, converted 'Castle' class frigates originally built for the Royal Navy in 1944, have now been operating as weather ships for about 14 years and still give reasonably satisfactory service, though now showing signs of their age. They co-operated with the two French ships and the Dutch ship *Cumulus* in operating station 'Alfa' on a part-time basis throughout the year and stations 'India' and 'Juliett' continuously. The rules and regulations governing the equipment and operation of the weather ships are administered by the International Civil Aviation Organization supported by the World Meteorological Organization. All ships make hourly surface and six-hourly upper-air observations (for heights reached in upper-air ascents see Table V of statistics). The following additional observations were regularly made by British Weather Ships: solar radiation and radiation balance, sea temperature and salinity down to considerable depths, magnetic variation and surface sea-water sampling. The biological sampling programme for the Institute for Marine Environmental Research was continued throughout the year, the Longhurst/Hardy plankton recorder being used to determine the vertical distribution of plankton in the upper 500 metres of the ocean at station 'India'. For this duty a marine biologist from the Institute made several voyages to the station. In association with this investigation into the plankton hauls, water samples for phytoplankton analysis were taken and extra net hauls for analysis of toxic residues in the plankton were made.

Communication and navigational facilities were available from all British Weather Ships for transatlantic aircraft and air–sea rescue equipment was kept in a constant state of readiness. Search and rescue exercises were frequently carried out in which Nimrod aircraft of the Royal Air Force sometimes participated. For the greater part of the year, the Meteorological observers on two vessels of the Sugar Line continued to make radiosonde observations as part of the World Weather Watch (WWW) programme for which service the Office is much indebted to the Sugar Line Management for their help and co-operation. Unfortunately the radiosonde aspect of the WWW programme for merchant ships did not develop as anticipated and the U.K. has decided to withdraw these two participating ships.

The Marine Division continued to co-operate closely with the Central Forecasting Office in the weather routeing of ships in the North Atlantic and in the North Pacific Oceans.

The number of marine inquiries, most of them from solicitors, shipping companies, universities and industrial firms, was about the same as for past years. The *Marine Observer* was published each quarter as usual.

Operational Instrumentation

The Operational Instrumentation Branch is responsible for developing, and introducing into operational service, a comprehensive range of data-acquisition systems in response to the needs of user branches. For several years the emphasis has been on equipment requiring less attention from observers, capable of operating at remote or relatively inaccessible sites and providing information in a convenient form for local interpretation or subsequent analysis by computer.

This emphasis is well illustrated by the two projects which receive special mention this year: the installation of the first Mk 2 automatic Weather Observing Systems (MOWOS) for use at remote land stations; and the successful completion of trials of the Mk 2 magnetic-tape Data Logging Equipment (MODLE) which will be used to record radiation and other variables at certain stations including the Observatories.

The first of 10 production MOWOS systems was delivered on time to the main trials ground at Beaufort Park and commissioned in June. By the end of the year, a further 5 systems had been delivered. Together with the sensors and interfaces (the latter developed and constructed within the Office) these systems enable synoptic measurements to be obtained over the public telephone network from nine sensors initially, most of these being well-established instruments. Stations equipped with receivers can interrogate any of the remote field stations, and receive data which have been updated every five or 10 minutes.

Tests of the first system at Beaufort Park revealed no transmission errors during some 1000 interrogations, and the data showed close agreement with nearby conventional instruments. Trials of the MOWOS network are now in progress, under the supervision of the Observational Requirements and Practices Branch, to determine the operational value of the scheme to forecasters. To date, remote field stations are in operation at South Farnborough and Leuchars.

Two of the new MODLE loggers were delivered and put through extensive trials before being accepted as replacements for the existing paper-tape

machines. They are the first of a range of climatological devices which will record on half-inch magnetic tape. A replay deck for translating these field tapes has been linked to the mini-computer at the Meteorological Research Flight (MRF), Farnborough until such time as the Bracknell mini-computer complex becomes available next year. The MRF configuration was fully operational for most of the second half of the year and provided reliable conversion of data from MODLE and three other prototype climatological recorders to a form compatible with the main IBM 360/195 computer.

Co-operative projects: national and international

Preparations for the Sixth Session of the World Meteorological Organization Commission for Instruments and Methods of Observation (CIMO) were started in February and involved three senior members of the Branch, together with a similar number from the Observational Requirements and Practices Branch. Two scientific papers were written for presentation at the Scientific Sessions and several working papers were submitted. The meeting took place in August at Helsinki, and was supported by a four-man delegation from the United Kingdom. Five officers of the Meteorological Office were subsequently appointed as CIMO rapporteurs or members of expert working groups.

As part of the work of the CIMO Working Group on Hygrometry, field trials were completed of two interim reference psychrometers (made locally to an internationally agreed specification) and analysis of the results begun. These instruments are intended for the eventual calibration in the field of station hygrometers in routine use.

Discussions under the European Economic Community scheme for Co-operation in Science and Technology (COST) continued on two projects. Under the project for the development and standardization of meteorological instruments, the Meteorological Office was awarded a contract to study the field of automatic weather stations and an officer of the Branch was appointed Chairman of a nine-nation working group to carry out the study. This group held its first meeting in November at Shinfield Park. Under the project for the setting up of a European network of oceanographic/meteorological buoys, it was agreed to work to harmonize the ocean data buoy programmes of the leading industrial members of the Community. The Shipping and Marine Technology Requirements Board of the Department of Trade and Industry approved the design concept of the British prototype data buoy (known as DB I), and tenders for this have now been invited. The main design work was carried out at the Institute of Oceanographic Sciences at Wormley, but the Branch has been made responsible for the meteorological sub-system.

There has been continuing involvement in the informal five-nation scheme known as the Joint North Sea Information System (JONSIS), and two Fisheries Laboratory, Lowestoft buoys were instrumented to provide wind measurements for a JONSIS exercise in the southern North Sea in the autumn.

The telemetering meteorological buoy, OBOE IA, was transferred to the Thames Estuary for the three months February to April, the receiving station being located at Shoeburyness. Valuable assistance with moorings and support vessels was provided by the Royal Navy and Port of London Authority (PLA). Data of good quality were obtained throughout the period and passed to London Weather Centre where they were used, *inter alia*, to provide special forecasts for the PLA. After overhaul, the buoy was redeployed in the Irish

Sea near Aberporth for the three months August to October and an additional measurement of lapse rate in the height interval 2–4 metres was incorporated. The reliability and quality of the data in both trials have been more than adequate to meet operational requirements, and the Branch has been asked to provide an operational version of the buoy to be known as OBOE THAMES. This will eventually be deployed in the Thames Estuary where its data will help London Weather Centre to provide weather forecasts to PLA for controlling the movement of large vessels up river.

Proposals for a co-operative drifting-buoy experiment have been accepted by the U.S. National Aeronautics and Space Administration from a consortium comprising the Fisheries Laboratory, Lowestoft; the Institute of Oceanographic Sciences, Wormley; the Directorate of Meteorology and Oceanographic Services (Naval) and the Meteorological Office. It is hoped that the buoys will be interrogated by the next U.S. research satellite NIMBUS F next year, their positions determined and their data relayed to the users for subsequent evaluation.

The Branch continued to provide the technical management of the Llandegla Research Station, and staff to operate the equipment, in support of the Dee Weather Radar Project. It is also handling the technical aspects of the contract for the conversion of the radar from S-band to C-band, and physical assistance was given to the Plessey Company during the on-site phase of the work in the closing months of the year. The modified radar became operational early in December.

It has been agreed to co-operate with the Home Office Police Scientific Development Branch and the Transport and Road Research Laboratory in a programme of comparisons of visibility sensors which show promise for use in the economic monitoring of visibility on motorways. Trials are planned for a site bordering the M4 motorway near Theale in Berkshire. The Meteorological Office's transmissometer will be used as the reference instrument.

The requirements for the observational programme for the two U.K. ships to be chartered for the GARP Atlantic Tropical Experiment (GATE) were referred to the Branch for detailed specification of the instrumentation and for arrangements for subsequent procurement and installation. The timetable, however, is uncomfortably tight and the task is made more difficult by the non-availability of the ships until literally the last day of two before sailing.

Development, production and evaluation of new instruments and systems

Following the successful field trials of the Mk 5 anemometer system last year, and the construction of a fully-engineered version in Meteorological Office workshops, the first operational system was installed at London/Heathrow Airport in April. Both the sensors and the telemetry links are duplicated in order to provide a thoroughly reliable service at the three sets of displays provided for the air traffic control, forecasting and remote observing office functions. Since this time, other installations of a less elaborate nature have been completed.

A second continuous automatic remote display (CARD) system has been installed to telemeter data from the Post Office Tower to the London Weather Centre.

A further 50 magnetic-tape event recorders (MTER) were manufactured for use with tipping-bucket rain-gauges, and these will be introduced into service in due course. Field trials of the prototype digital anemograph logging equip-

ment (DALE) showed the need for modifications, but these have now been completed and the revised equipment was made available for user evaluation trials towards the end of the year. DALE automatically extracts the essential statistics of a wind trace and records these hour by hour on half-inch magnetic tape.

The first prototype of a simple agro-climatological recording equipment (ACRE) was developed and a preliminary field trial begun. Signals from up to four sensors are converted to trains of events and recorded (in duplicate) on four pairs of tracks on a special 10-track MTER. The remaining pair of tracks is used for time marks. The system is economical but it remains to be seen whether sufficient resolution can be provided to satisfy user requirements.

Intense contractual activity has continued throughout the year on the Mk 3 radiosonde project. Several more production contracts were placed, culminating with orders for 25 000 radiosondes, and major tendering exercises for the automated ground stations and central calibration plant were well advanced at the close of the year. Once these contracts are placed, the project will be entirely into the manufacturing phase but the resources of the Branch are being stretched in the testing and quality control of components already being delivered for the new radiosondes. Work was completed on the provision of details of the basic computational programmes for the eventual system which will need to be programmed by the manufacturer of the selected computerized system, and additional software routines were written for coding up the meteorological report messages and for transcribing the data to archives. Progress on all aspects of the project has been monitored and close liaison between the many groups involved has been maintained by the regular use of project evaluation review technique (PERT) charts.

The improvement in the performance of the high-altitude balloons obtained from an alternative manufacturer, which was discernible towards the end of 1972 has been satisfactorily maintained. This can be seen in the figures given in Table V. For the first time, an appreciable percentage (30 per cent) of these ballons reached 7 mb (33 km) on midnight flights, and this means that balloons are now available to enable the potential of the Mk 3 radiosonde to be realized. Trials of new types of British-made balloons at radiosonde stations have also shown improved performance and the scope of these trials is being widened. A programme has been started to evaluate alternative types of radar reflectors, partly in connection with the Voluntary Assistance Programme of WMO and partly in an attempt to reduce the heavy expenditure on these consumable items.

In the field of sensor developments, the concentration in recent years on instruments for measuring humidity has culminated in the establishment of a range of devices to meet a wide variety of operational requirements: thus electrical resistance psychrometers are available for most automatic measurements, and these can be supplemented by lithium chloride hygrometers (dewcels) where sub-zero temperatures are likely to be encountered or by PCRC hygrometers (so called after the initials of the manufacturers) on buoys and at remote battery-operated stations where power is very limited. The field trials of three automatic sunshine transducers have shown that the results are closely reproducible between instruments, and that there is good agreement with the Campbell–Stokes recorder for daily periods. These devices are being introduced into service with MOWOS to provide an indication of state of sky,

but their potential value in the climatological field will also be investigated. As part of the programme for developing a replacement for the existing cloud-base recorders (CBR) a critical appraisal of the present optical and electronic systems has been carried out. A series of experimental modifications of an existing instrument at Beaufort Park has been planned in order to determine the design parameters for the new CBR. A system has been developed for measuring rainfall on vibrating or moving platforms such as oil rigs and ships. This comprises an aerodynamically efficient rain collector for mounting on a high mast, a peristaltic pump which provides an electrical pulse each time it delivers a calibrated quantity of rain-water and an MTER which records the temporal distribution of the rainfall in terms of pulses against time. Trials are scheduled for an oil rig in the North Sea and on an ocean weather ship before the system is installed on the two U.K. ships to be chartered for GATE next year. A long-standing problem has finally been solved, namely that of averaging wind direction from a vane which provides a discontinuity from zero to maximum signal when the wind fluctuates about north. This important new development is being incorporated in the MOWOS interface for the wind-direction channel, in the latest versions of DALE where useful economies in tape usage have resulted and also on the telemetering buoy OBOE I where the device is combined with a digital wind vane and compass.

Technical management

Over the past few years, the overall workload of the Branch has grown faster than available resources, whether in terms of manpower, finance or facilities. This has required firstly that individual projects have had to be controlled more closely, not only so as to take up expenditure provisions in the right year, but also to take up allocations of, say, workshop or drawing office effort at the right time. Secondly, and much more difficult to bring about, each of the separate projects is now having to be planned in relation to the others so that common facilities such as the capacity of the test laboratory or installation section to handle new equipment are not saturated. In addition to exerting tighter budgetary control, the Branch has had to maintain a system of records of utilization of the time of development sections, workshops and drawing office, and of the consumption of materials and components, in response to the gradual extension of central management accounting in the Meteorological Office. In many of these areas, the introduction of costing of the activities of the research branches has entailed the submission of special returns detailing the effort expended by the Branch on research projects. The use of PERT charts as an aid to the planning and control of major projects has already been mentioned in connection with the Mk 3 radiosonde project where it has proved indispensable; it had already proved of value in the MOWOS project, and will be used in the planning of the integrated data acquisition and telecommunication system for the new ocean weather ships. Initial studies for this have been started in co-operation with staff of the Telecommunications Branch.

A preliminary study has been made on the possibilities of setting up a computerized fault-reporting and analysis system to monitor the performance of routine equipment in the field. The absence of such data is a serious impediment to the efficient work of designers, maintenance staff and those responsible for technical management and policy, but lack of staff will probably make progress in implementation rather slow.

Technical services and facilities

The move of the wind-tunnel from the Dines Wing to Eastern Road was completed, and the Department of the Environment has provided new thyristor-controlled equipment for the fan motor to improve the stability of the airflow, particularly at low speeds. Accommodation in the original Field Station at Beaufort Park has been rearranged and room made available for the Regional Radiation Centre which moved from Kew Observatory and for the Bracknell Regional Servicing Centre which had previously been at Eastern Road. At the same time, the opportunity was taken to improve the accommodation arrangements for the training school for technicians and for two of the physical research branches. More extensive alterations have been completed in the main headquarters block at Beaufort Park. Office accommodation and two optical laboratories have had to be provided for the work of the staff transferred from Kew who will be responsible, within the Branch, for radiation instrument development and calibration. Assembly of the necessary equipment and facilities is going ahead and there will be a thorough intercomparison of standards and procedures at Kew and Beaufort Park before work in this field at the former is finally closed down. Accommodation has also been made available for a new satellite picture receiving centre for staff of the Telecommunications Branch and for a newly created technical writing section. In addition, the Chief Instructor moved from the Field Station and the Head of Test and Calibration transferred from Western Road; the last two moves will make for more effective liaison between sections. Two years after the main move to Beaufort Park, the available accommodation is now only just adequate. As will be seen from the above the Branch has continued, in co-operation with Office Services, to manage the Beaufort Park site on behalf of all users and to promote the optimum utilization of both accommodation and facilities.

While the main mechanical workshop at Beaufort Park and the small workshop in the Dines Wing have been fully loaded throughout the period, the new system of unified control has worked satisfactorily and all requirements were met until the closing months of the year when staff deficiencies began to appear again. The Branch's use of workshop services has increased slowly over the past two years from 40 to 50 per cent. The small electronic workshop has been under heavy pressure, particularly because of growing demands for construction of prototypes, fully engineered pre-production prototypes and, in one or two special cases having operational priority, professionally manufactured 'one-off' systems. Some relief was provided late in the year by the short-term detachment of some Llandegla Research Station staff who were made available through the closing down of their normal activities during the on-site conversion of the radar for C-band operation. The engineering drawing office was again inundated with work on specifications and manufacturing drawings for production items such as the Mk 3 radiosonde system and MOWOS, most of which has to be carried out by outside contractors. Forward projections have shown, however, that with the tailing off of work on these major projects there will be a slight reduction in the level of outside contract work next year.

Aerological support services were provided for the international comparisons in May of the Finnish reference sonde with the Mk 3 radiosonde (see the Observational Requirements and Practices section of this *Report*) and for special activities of research branches and other government departments. Assistance was also given to the Department of the Environment by flying tethered balloons

on two occasions. Experience gained with the prototype rotatable balloon-filling shelter has shown that the design is generally sound. With an internal height of 9 m and a width of 5·5 m, the largest radiosonde balloons can be filled without difficulty. The structure is then turned by two electric motors until the electrically operated door faces downwind. The aerodynamic shape derived from wind-tunnel studies, minimizes eddy effects and makes launching much easier in high winds (see Plate VIII). The increasing involvement of the Branch in data-recording systems, translation devices, computerized real-time processers and computer-based calibration and quality-control systems has required the closer co-ordination of mathematical services and data-systems support activities. A small group has been formed to deal with this rapidly growing field and to liaise with the Systems Development Branch, which is responsible for advice and overall policy on such matters.

Technical liaison and equipment installation

Apart from the continuing burden of work on the Mk 3 radiosonde and MOWOS contracts, the work associated with the contracts for magnetic-tape event recorders and data loggers and cross-wind resolvers was less demanding and has now been completed. Technical inquiries from users, manufacturers and other government departments continued at a high level; the production and dissemination of specifications and technical documentation for the manufacture, testing, installation, operation and servicing of equipment also required considerable effort. In addition to equipment mentioned in previous sections, three 10-cm wind-finding radars, four cloud-base recorders and three data print-out equipments for wind-finding radars were installed. Work is nearing completion on refurbishing the 10-cm weather radar, formerly at Singapore, for installation at Watnall next year. The post-design services section dealt with a number of problems, mainly in the radar field, and was again concerned with work on the experimental Mk 1 MOWOS at the Lichfield IBA mast.

Instrument testing, calibration and standards laboratory

Table XV shows the numbers of instruments and items of equipment which were tested or calibrated during the year. Deliveries of Mk 3 radiosonde components increased sharply in the latter half of the year and in some cases testing them required the development of new techniques and facilities. At the outset of production in quantity, there is a need to analyse the population characteristics of these components in order to apply quality-control procedures on later deliveries. Calibration of Mk 2 radiosondes continued normally at first, but staff shortages in the last quarter of the year caused a fall in throughput as a result of which the stockpile of calibrated sondes began to dwindle.

Acceptance testing of MOWOS is being carried out at the factory; this is taking up considerable technical effort as is also the testing of the modernized facsimile recorders. The latter have not so far proved satisfactory, and further effort will be required of the manufacturer if the hoped-for reduction in maintenance time is to be achieved.

The position as regards standards is reasonably satisfactory for the time being, and reflects the steady progress made in this area in recent years. Work on improving the facilities in the thermometer-testing section was completed, and the laboratory is able to offer a comprehensive service for calibrating all types of meteorological thermometers.

Servicing and technical training

With existing numbers of staff it became increasingly difficult for the Regional Servicing Organization (RSO) to maintain and inspect the steadily growing volume of equipment in the field. As first reported last year, studies are in progress to determine the optimum level of maintenance, the best methods of servicing (taking into account recent trends in solid-state circuitry and improved reliability), the most suitable centres at which to carry out each of the different aspects of servicing and repair, and particularly the most efficient partitioning of the total workload between the existing and possible future servicing centres. In the latter connection, the Branch has continued to work with an operational research consultant from the Civil Service College on the development of a computer model of the RSO. This is capable of looking at the servicing requirements of over 250 stations in the U.K., the logistic effectiveness of each of the 17 parent servicing centres, and the mileage and travel-time implications involved in making over 3000 man-visits per year to service some 700 instruments.

Controlled experiments in which the extent of preventative maintenance was varied over wide limits have already led to significant savings in technicians' time spent on some equipment. The RSO has been involved in the preliminary trials of the modernized facsimile recorders and, although results have been initially disappointing, the experience will be valuable in the main trials. The increasing diversity and complexity of instrumental systems in operational service have required a thorough reappraisal of training courses and methods of instruction for the technicians who service equipment in the field. Emphasis is now placed on the rapid diagnosis of faults down to sub-module level, followed by printed circuit board (PCB) replacement on site and subsequent repair of the PCB at a regional or central workshop, as the best way of reducing 'down time' on the equipment concerned. This makes optimum use of recent changes in the technology but requires some changes in training philosophy in line with current field practice, and corresponding changes in spares holdings.

Computing and Data Processing

The Data Processing Branch operates the IBM 360/195 scientific computer, and most of the data-preparation equipment including the processer-controlled data-entry system, and punched-card pool. It is responsible for the software requirements for computer operation, including typewriter and cathode-ray-tube terminals; and for the programs within the IBM 360/195 to interface with the telecommunication systems. It is also responsible for general-purpose programs to store, quality-control, and retrieve observational data received from the telecommunication systems and to produce plotted and line-drawn charts and graphical displays required mostly for day-to-day operational tasks. An Enquiry Bureau maintains liaison with computer users, offering advice as required and providing (mostly for external inquiries) a limited service of data extraction from machinable archives.

Meteorological Computing Laboratory—IBM 360/195 *computer*

By the end of 1972 most of the planned changes to the IBM 360/195 configuration had been completed and most of the major operational tasks implemented. Therefore 1973 saw comparatively few changes in equipment and

much of the software effort was designed to improve the overall operation of the systems already running, especially those fulfilling operational requirements, a major new effort being confined largely to implementation of the standby procedures for the 10-level octagon forecast model at Rutherford High Energy Laboratory (RHEL), required in event of processer failure at Bracknell, and development of line-drawing and plotting programs to meet the operational requirements of the Central Forecasting Office (CFO) and outstations.

Through the co-operation of the staff at RHEL procedures to run the 10-level octagon forecast model at RHEL were developed by joint efforts of the Central Forecasting and Computer and Data Processing Branches. A considerable effort is required to develop and maintain such procedures which must run without fail under the operating system in use at the time at RHEL and which cannot be tested without considerable inconvenience to RHEL. The facilities available for standby are excellent in most respects excepting paper-tape input which is barely adequate for handling the current meteorological data required to compute a forecast. However, with the help of the Transport and Road Research Laboratory, Crowthorne, Berks., arrangements were made to transfer paper-tape data to magnetic tape which can be read with ease at RHEL. Also the line printers at RHEL are not wide enough to print the full forecast output but CFO and outstations have agreed to accept this restricted cover in emergency. Standy arrangements to run the old 3-level forecast suite on the KDF9 computer at the Admiralty Research Laboratory, Teddington, were maintained until the procedures at RHEL were fully developed. One computer failure occurred in May which necessitated a standby run at RHEL.

In January an on-line interface and a 16-mm camera for the Calcomp 1670 Computer Output on Microfilm (COM) equipment passed acceptance trials and in July two off-line Calcomp 915/1136 electro-mechanical drum plotter systems were also accepted. This provided a minimum configuration for operational line-drawing and plotting functions and throughout the year there was continuous development of programs to provide plotted and line-drawn charts for operational use in CFO and for transmission by facsimile to outstations.

Printed copies 22 in × 18 in (56 cm × 46 cm) of line-drawn and plotted charts are produced in CFO from the microfilm output of the Calcomp 1670 COM equipment. These prints are used both by CFO staff and also for transmission by facsimile to outstations. Large plotted charts up to 33 in × 28 in (84 cm × 71 cm) covering the whole or a large part of the northern hemisphere are produced by means of the 1136 drum plotters using special continuous pre-printed stationery. The technical quality of the output from both types of equipment has been high from the beginning, but considerable effort has gone into developing methods of operation to meet the very tight time schedule of CFO requirements. Observational data are still received from the telecommunication systems as punched paper tape and it is not practicable to provide this to the 360/195 more frequently than every 20 minutes. Printed (page copy) data for hand plotting can be provided at shorter intervals and hence, although automatic plotting is intrinsically faster than hand plotting, output is not likely to be available any earlier until data from the telecommunication systems are provided earlier and more frequently by means of a direct interface to the IBM 360/195 (see below). Also it is impossible to revert from automatic plotting to hand plotting and still produce all charts to the

required schedule because the current schedules are only achieved by hand plotting in parallel with the continued receipt of data on the telecommunication channel. Consequently, there must be alternative automatic plotting facilities to cover failure of the primary equipment; also without an alternative computing facility some failures must still occur. If the Calcomp 1670 COM system fails it is just possible to produce all the requirements using the 1136 drum plotters although some output may be delayed during the change-over period. However, both equipments proved very reliable during tests by the Branch lasting several hours each day during August and September, and in November CFO released several Assistant Scientific Officers for training in the operation of the automatic plotting equipment in preparation for a full-scale operational test in November and December. The full potential of the service cannot be developed until the interface between the telecommunication systems and the IBM 360/195 is implemented. Also an additional plotter and an alternative computing facility may be necessary to provide the dependability which is essential for an operational service of this kind.

Changes to the operational data-handling and numerical-forecasting suites were introduced continuously throughout the year to improve the speed, scope, and effectiveness of the service and at the same time to minimize its effect on the throughput of batch work for the main programmers in headquarters branches. Operational runs of the synoptic data bank suite have increased steadily throughout the year to provide data for new requirements including automatic chart plotting, objective analyses and displays on the IBM 2250 cathode-ray-tube device based on current data. Many small changes were made in the data-bank suite to improve recognition, quality control and retrieval of data and to incorporate additional codes including one for temperatures obtained from satellite data. Design changes were made to the data-bank suite to improve the running of priority data-bank programs and operational working depending on them, without unduly restricting the mix and flow of the less critical batchwork. At the same time the overall core storage requirement was reduced by about 14 per cent. A considerable effort was applied to documentation of the synoptic data-bank facilities and a document on the use of retrieval facilities was published in June. Also, the backlog of archiving the synoptic data bank to magnetic tape for January 1971 was finally cleared in June and all subsequent archiving kept up to date on a daily basis. The flow of data to the synoptic data bank from the Global Trunk Circuit was monitored for a period in May to provide the Telecommunications Branch with a means of analysing the flow of data for a report to the World Meteorological Organization.

Many small changes were also made to the operational-forecasting suite based on the 10-level octagon model introduced in August 1971, including changes in output methods, implementation of new chart reprints and paper-tape output of data in the new GRID code for the digital transmission. Larger changes included twice-daily operational analyses of two data fields, based on an orthogonal polynominal fitting technique developed in the numerical forecasting section of the Central Forecasting Branch and required for CFO and forecasting units at outstations. Later in the year extensive tests were made with the new analysis technique to assess its suitability as a basis for producing the initial fields used in the main operational forecasting suite.

The 10-level rectangle forecast suite, which covers much of Europe and the

North Atlantic, was run twice daily throughout the year, with 12-hourly updating runs from March, to provide the Forecasting Research Branch with facilities for continuously developing the model for forecasting in the area of the British Isles. The Forecast Research Branch introduced semi-implicit methods of computing these forecasts, thus saving considerable amounts of computing time and minimizing the effects of these tests on other computer users.

Smaller regularly run services not directly connected with daily operational forecasts included programs to support printing of the *Daily Weather Report*, introduced from 1 January, and its *Overseas Supplement*, introduced on 14 April.

Some progress was made in transferring the very large library of punched-card data to magnetic tape. About 4 million cards were written to tape and inquiries are being made to ascertain whether some of the information currently available in the U.K. on cards only, is available on magnetic tape in the U.S.A.

Operating-systems software support has consisted mainly of the introduction of a new operating system, which although not without its problems, removed a number of difficulties and errors in the previous system. The opportunity was also taken to make some alterations to system-generation options and to improve the support and facilities for disc exchanges which reached a high level during the year. A considerable effort was expended in improvements to support typewriter and visual-display (VDU) terminals including the 2250 graphics terminal in CFO. The Meteorological Office modifications to the IBM software Conversational Remote Job Entry (CRJE) package, to support IBM 3270 VDUs and associated IBM 3284 printers have proved successful and two approaches were received from other installations to use the package. In March a remote IBM 2741 typewriter terminal was installed at the Meteorological Research Flight, Farnborough, and the last two of five IBM 3270 VDUs were installed at headquarters. However, terminal facilities were restricted to two hours per day during week days—largely because of lack of main core storage—and work to rewrite the IBM-support to work in less storage proceeded only slowly.

Services for the limited number of agencies using spare capacity in 1972 were maintained throughout 1973 but spare capacity is now largely confined to week-ends and is decreasing steadily. Possible hardware enhancements to enable the full potential of the IBM 360/195 to be realized and to provide for the steadily increasing operational work load were investigated in conjunction with the Systems Development Branch and the Computer Management branches of the Ministry of Defence and Civil Service Department. As a result of these investigations an order was placed in December 1973 for a front-end processer (IBM 370/158) to be delivered early in 1975. Prior to the formation of an Automated Telecommunications Planning team for the Office, certain staff of the Computing and Data Processing Branch were actively involved in collaboration with the Telecommunications Branch on the implementation of Phases I and II of the Automated Telecommunications System. Computing and Data Processing Branch staff also assisted in the definition of an interface between the Myriad telecommunication computers and the IBM 360/195 system. This interface is intended for early implementation to remove most of the operational constraints produced by the current dependence on paper tape for transferring data to the IBM 360/195.

COMET computing laboratory

The operational working day of the ICL KDF9 electronic computer (COMET), which was installed in 1965, was reduced to cover the period 0800–1700 from Monday to Friday with effect from 1 January. Finally at 1600 on Friday 30 March it was powered down for the last time. Work submitted to the KDF9 continued at a high level right up to the final shut-down and arrangements had to be made for some residual work to be completed at Teddington on the KDF9 serving the Admiralty Research Laboratory and the National Physical Laboratory.

The KDF9, not being required by any other government department, was eventually disposed of through normal commercial channels and was removed on 2 November.

Punched-card and processer-controlled keying installation

The punched-card installation, which at the beginning of the year was equipped with a range of punched-card machines including punches and verifiers, sorters, collators, tabulators and tape/card converters, was considerably modernized and streamlined. As a culmination of studies, and later discussions with the manufacturers which had begun during 1972, the punch room containing punches and verifiers was re-equipped with a Redifon 'Seecheck' processer-controlled keying system. This comprised a basic control group incorporating a processer with 32 K (K = 1024) 16-bit words of core storage, a tape transport (9-track, 800 bits per inch), a magnetic-disc drive with 2·8-million bytes capacity and 17 keystations, one being dedicated to supervisor actions. The delivery date was Wednesday 21 February and following a trials and training period the system had taken on almost the whole of the operational load before the end of March and was fully operational early in April. Subsequently the remainder of the punched-card processing equipment was reduced by about half as most of the data processing that had been carried out in the machine room was transferred to the main frame computer.

Finally arrangements were made for the smaller program punching pool now using IBM 029 and 059 machines to be equipped with IBM 129s. At the end of the year delivery of the new equipment was imminent.

Systems Development

The Systems Development Branch keeps abreast of new developments in computing science and data processing with an eye to present and future needs of the Office, and also designs and implements systems for carrying out such tasks as they arise. The first major project, now well under way, is the build up of the meteorological archives into a well-ordered, indexed data library. All the data on the old KDF9 computer were designed for rapid serial access—all that is possible from magnetic tapes. The new IBM computer has large random-access disc stores from which it is relatively easy to retrieve individual data items from any data set within the library. In order to facilitate this, each archived data set contains an index and, if necessary, cross-reference tables which will help in the search. To make the task even easier for the programmer, general-purpose routines have been developed to find and retrieve just what is wanted.

To assist forward planning a survey was made early in the year of current computer usage within the Office, and of the likely work load over the next few years. At present less than half the processing power of the IBM 360/195 can be used because the available main storage limits the number of programs that can be executed concurrently; there are a number of ways of relieving the situation, including the provision of an additional (front-end) processer. Concerning long-term requirements the Branch maintains contact with the big computer manufacturers, and two of its members toured the United States in October to see the latest equipment there, and to discuss future possibilities in the general areas of computer architecture, mass storage and telecommunication processing.

An order was placed with the Digital Equipment Corporation for a PDP11/40 mini-computer for delivery early in 1974. In addition to its prime role of transcribing to computer-compatible forms data cassettes from the new data-logging devices developed in the Instrument Development Branch, it is intended to test the effectiveness and practicability of applying computer-based systems to the functions of the Office. To this end besides the normal peripheral devices (card reader and printer), a cassette drive and a 9-track magnetic-tape drive for the data-logging task, the mini-computer will also start with a magnetic disc unit and an interactive graphics visual display unit. Further devices can be added as required.

Meteorological archives

Many of the meteorological data on magnetic tapes readable by the old KDF9 computer have now been transferred to tapes readable by the new IBM 360/195 computer; but there are still many more to be transferred. At the same time newly acquired data (since January 1972), and many of the old punched-card series of data are being read to tape. For instance, during the year all the global historic marine data (1854–1960) on cards—observations that have been made largely by voluntary observers aboard British merchant ships, totalling 6 million observations—have now been converted to magnetic tape. There they will eventually be joined by another 20 or 30 million observations that have been made by foreign ships: these are to be copied from the American collection of marine data which has been collected, sorted and vetted at the National Climatic Center in Ashville, North Carolina. From 1961 onwards marine data are to be preserved in international collections, the United Kingdom being responsible under a WMO Resolution for an area of the North Atlantic west of 20°E, east of 50°W and north of 20°N, including the North Sea (but not the Baltic).

Other large collections of card data include those of observations made (every hour in some instances) at stations in the United Kingdom and at a few overseas stations. Five or six million of these observations (mostly beginning in 1957) have now been transferred to magnetic tape and are being used for climatological investigations. New (hourly and fixed-hourly) observations from U.K. stations are accumulated as received from postal returns via the Seecheck data-entry system into special monthly data sets. Although these data sets reside on dismountable disc packs they are mounted on the computer every night for updating, and are used regularly by the Climatological Services Branch for preparation of the *Monthly Weather Report* among other tasks. Returns of daily observations, temperature extremes and rainfall totals are treated in a

similar way so that, by half-way through the month following that of the observations, hourly and fixed-hourly observations for more than 100 stations, daily observations for more than 600 stations, daily rainfall totals for nearly 5000 stations and monthly rainfall totals for nearly 7000 stations are gathered on to magnetic discs from which they can be retrieved at high speed.

To cover the remainder of the world, daily extractions are made from the synoptic data bank of the Computing and Data Processing Branch. These comprise all surface observations—upper-air observations remain a separate exercise—and the same fast retrieval can be applied to the resulting data sets, in which the data are classified and sorted into type and order. Two of these data sets are used to prepare tapes to construct each *Daily Weather Report* and a third which contains daily extreme temperatures and rainfall totals for 1750 stations in Europe and Africa can be used for forecast verifications.

Two small data sets are being constructed which are of special interest because they will eventually permit the immediate answering of general climatological inquiries. One set contains the descriptions and geographical details of all U.K. rainfall stations that were in use since 1960—at present the list contains information for just under 10 000. The other set contains at present some only of the details for the 650 or so climatological stations observing during 1973; but these include monthly averages.

Software development

In order to achieve rapid access from disc, archives data sets have been designed with standard positions for control parameters and indexes to the contents of the data sets. The parameters are used to describe the dimensions of individual blocks or parts of blocks within a data set and thus permit a wide range of individual records to be stored with little waste space, and at the same time permit rapid access by no more than two general-purpose programming routines. The indexes are intended for use in much the same way as the index to a large encyclopedia; however, since consultation of the index is provided by the access routines the index can be more hierarchical and 'consulted' along several different headings according to the requirements of different users. Two access routines are provided, one of which caters for data which can be stored in fixed-length records with little waste space (some is inevitable); the other caters for variable-length records. Both routines became operational during the year after lengthy field trials.

The IBM 360/195 computer has attached to it a number of visual display units. Normally use of these devices requires assembly-language programming and heretofore has been restricted to special purposes such as program amendment and entry of programs into the job queues within the computer. A special programming module called TALKBACK has now been developed which will enable programs written in simple FORTRAN to have on-line access through a visual display unit to an operator who can then not only enter new data or correct old data but can within limits also control the next actions of the FORTRAN program. The limits are neither more nor less than what the FORTRAN programmer chooses to make them. The most likely uses of this new facility will be to explore, retrieve or amend meteorological archives.

The slower line-printer (1000 lines/minute) on the IBM computer has the additional facility of a special print train, which allows a fuller range of characters to be printed than the normal printers, and also includes the facility

to print sideways on the page. First attempts to use the device showed the difficulties but during the year a programming package was developed which eases the job for the programmer and, in addition to tabular layout either way on the page, allows the plotting of graphs and the printing of elementary mathematical formulae.

Data conversion

The field logging devices for recording meteorological data are designed to record on magnetic-tape cassettes. These are 10-channel tapes without inter-record gaps, and so have to be read by a special replay deck attached to a mini-computer. At present the tapes are being read by a deck attached to the mini-computer at the Meteorological Research Flight at Farnborough. This tape-deck will be moved to headquarters for attachment to the new mini-computer on installation early in 1974.

Cataloguing of literature and data

The first feasibility study of further automation of the National Meteorological Library was completed in the spring. This showed that the substitution of a computer-assisted data-entry system for the punching of paper tape via flexowriter could save a lot of work and remove some difficulties in the preparation and expansion of the various library catalogues. The addition of a few characters of control information will permit the automatic production of even more useful catalogues. A pilot project is being mounted to try out some of these ideas.

To extend the system and keep the catalogues on line and permit retrieval via terminals would demand a dedicated mini-computer as well as a number of display units within the library and at strategic points at headquarters and elsewhere. Such a system is known to be feasible but demands at least five years' data to be worth while—and the information now preserved from the *Monthly Bibliography* only started in January 1972.

Automatic reading of automatic traces

The method of using the computer-controlled flying-spot cathode-ray-tube (CRT) scanner at the Nuclear Physics Laboratory, Oxford University, to read pen-and-ink traces moved from the experimental to the field-trials and then the routine stages for rainfall traces. The general procedure is:

(a) to prepare a special punched card on the IBM 360/195 from relevant data for each month's rainfall traces,
(b) to photograph this card and the traces on 16-mm microfilm (5 years on each film),
(c) to read and analyse by CRT scanner at Oxford producing digitized values on magnetic tape (the analysis can be done at 2000 charts/hour but usually achieves about 600 charts/hour),
(d) to read this magnatic tape on the IBM 360/195, store the data in an archive format on IBM tape which can subsequently be read using the first of the access routines described previously, and
(e) to use the digitized data on request, to re-create the trace on the Calcomp microfilm plotter attached to the IBM 360/195. Samples of the original rainfall chart and the corresponding re-created trace derived from the

digitized data are illustrated in Figure 3. They indicate how successfully the information content of the original trace is preserved in the digital form.

Owing to staff shortages only a very limited effort has so far been applied to investigating the possibility of using the same device to analyse anemograph traces.

Meteorological Telecommunications

Although the telecommunication facilities and services of the Meteorological Office comprise a fully integrated single system, some parts have a predominantly national character while other parts are more involved internationally. As far as the latter are concerned, the main achievement during the past year has been to bring the Bracknell Regional Telecommunication Hub (RTH) into full operational service on the World Weather Watch (WWW) Main Trunk Circuit (MTC), operating in the data-transmission mode at 2400 bits/s together with analogue facsimile transmissions on a time-sharing basis. This achievement followed a period of some months reaching back into 1972, during which extensive operational trials were carried out between Bracknell and the associated main trunk centres at Washington, Paris and Offenbach. The new Washington–Bracknell high-speed transatlantic connection was upgraded in April to become the primary route between North America and Europe for the exchange of meteorological information. As regards the national aspects, steps have been taken to improve existing teleprinter and facsimile services by replacing old equipment with that of more modern design and construction. Considerable effort has also been devoted to the planning and reorganization of the basic U.K. meteorological telecommunication networks, particularly in order to optimize the benefits derived from automation within the Bracknell Telecommunication Centre.

Implementation of Bracknell RTH and associated MTC segments

In the *Annual Report* 1972 it was stated that the Bracknell RTH and the main trunk segment Washington–Bracknell had been placed on full operational status on 1 November 1972. This was in respect of high-speed data transmissions at 2400 bits/s, with full error control, for messages in alphanumeric format. The problems associated with handling analogue facsimile transmissions over the same MTC, including the necessary data/facsimile switching procedures, had by no means been solved. It was realized in the MTCs of Washington, Bracknell, Paris and Offenbach that further delays were inevitable owing to the acute technical problems still remaining to be solved, and staff shortages existing at Bracknell, Paris and Offenbach. Accordingly a meeting was held in Paris during the first week in February in an attempt to find answers to the technical problems.

Because the situation, as seen at Bracknell, was that the technical problems were mainly in the data/facsimile switching and facsimile transmission areas, the Bracknell representatives argued for separating alphanumeric data transmission from facsimile transmission for the time being. The meeting agreed to this and as a result full operational status for alphanumeric data on the MTC from Washington through Bracknell and Paris to Offenbach was achieved on 8 February. For several years the primary transatlantic route for the exchange

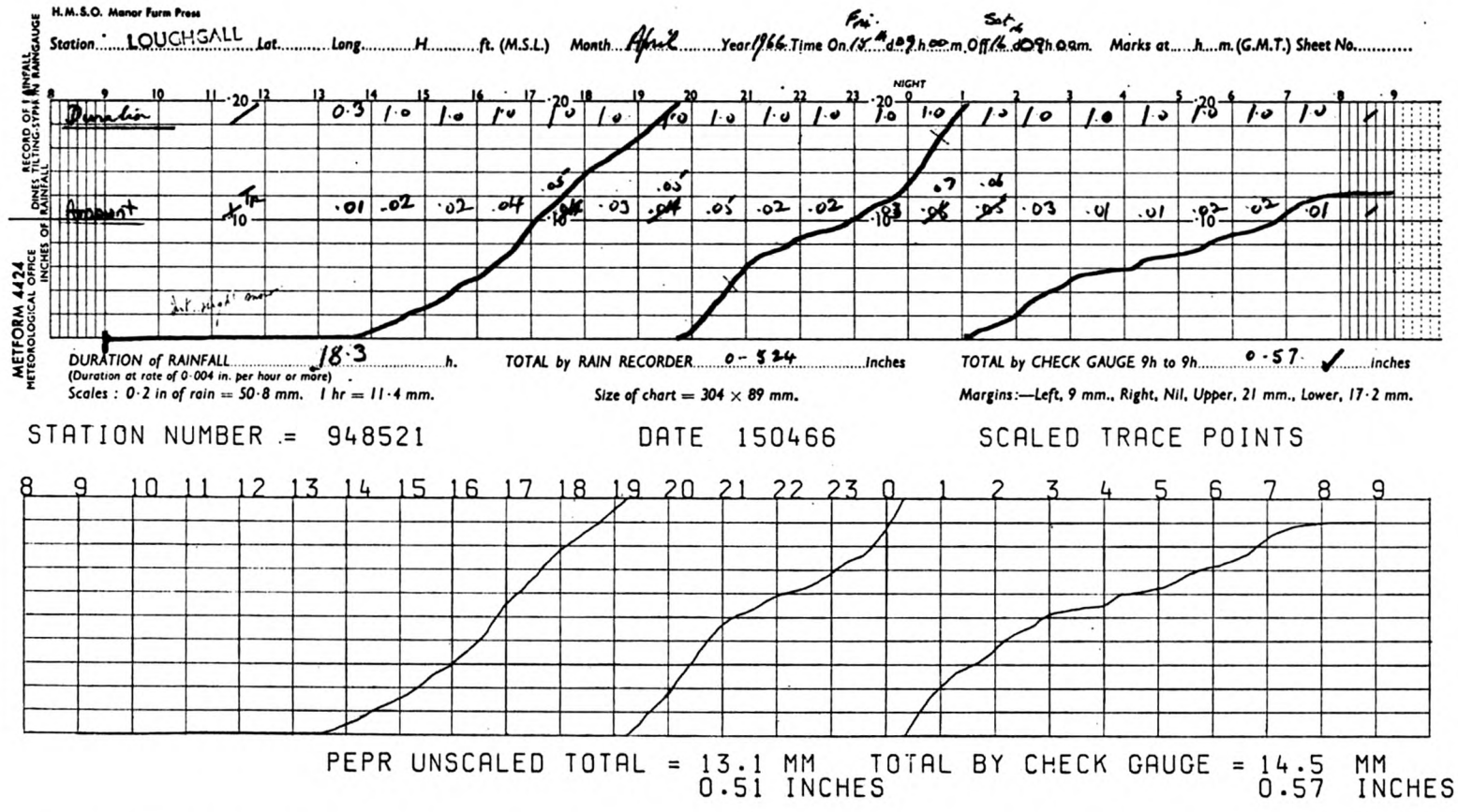

H.M.S.O. Manor Farm Press
Station LOUGHGALL Lat. Long. H. ft. (M.S.L.) Month April Year 1966 Time On 15th d 09 h 00 m Off 16 d 09 h 00 m. Marks at h. m. (G.M.T.) Sheet No.
RECORD OF RAINFALL
DINES TILTING-SYPHON RAINGAUGE
METEOROLOGICAL OFFICE
METFORM 4424
INCHES OF RAINFALL
NIGHT
DURATION of RAINFALL 18·3 h.
(Duration at rate of 0·004 in. per hour or more)
TOTAL by RAIN RECORDER 0·524 Inches
TOTAL by CHECK GAUGE 9h to 9h 0·57 inches
Scales : 0·2 in of rain = 50·8 mm. 1 hr = 11·4 mm.
Size of chart = 304 × 89 mm.
Margins:—Left, 9 mm., Right, Nil, Upper, 21 mm., Lower, 17·2 mm.
STATION NUMBER = 948521
DATE 150466
SCALED TRACE POINTS
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 0 1 2 3 4 5 6 7 8 9
PEPR UNSCALED TOTAL = 13.1 MM TOTAL BY CHECK GAUGE = 14.5 MM
0.51 INCHES 0.57 INCHES

FIGURE 3—ORIGINAL TRACE OF HYETOGRAM FROM LOUGHGALL, 15 APRIL 1966, COMPARED WITH A RAINFALL TRACE CONSTRUCTED FROM DIGITIZED DATA PRODUCED BY PEPR

The figures in pencil on the hyetogram are the observer's estimates of hourly durations and intensities in inches. In the trace produced by PEPR due allowance has been made for fly-back (whilst the reservoir empties) and the data scaled to make the recorder total agree with the check-gauge.

Hourly statistics (beginning at 1300) derived from these scaled values are:

Duration (h) ...	0·4	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	0·9	1·0	1·0	1·0	1·0	0·1
Amount (mm) ...	0·2	0·6	0·7	1·2	1·2	0·8	1·1	1·5	0·6	0·5	0·9	1·7	0·8	0·8	0·2	0·4	0·5	0·6	0·3	tr

of basic meteorological data had been a 1050-baud circuit between Washington and Offenbach with spur circuits from Germany to Bracknell and Paris. From 8 February this 1050-baud network was placed on standby status.

By the middle of March it was clear that the problems of main trunk data/facsimile switching and the store-and-forward of facsimile products from centre to centre were still by no means solved. Difficult problems were of course inevitable in a situation where the telecommunication staffs at the four centres were dealing with an entirely new type of computer-controlled communication system with crucial requirements for compatibility of operation between adjacent centres. A further meeting was therefore held in Paris towards the end of March following which operational trials of facsimile transmissions along the main trunk were intensified. Meanwhile data transmission of observational and other data in alphanumeric format continued smoothly with only occasional snags arising and for these data the high-speed circuits from Paris and Offenbach were placed at full operational status, with effect from 13 April. This meant that together with the Washington high-speed link (already used operationally for the previous few months), the national requirements for basic meteorological information from Europe and North America, as well as from parts of Africa, Asia and large ocean areas, could be received using the new components of the Global Telecommunication System (GTS). The printed page copy of the teleprinters associated with the International Meteorological Teleprinter Network in Europe (IMTNE) was simultaneously relegated at Bracknell to a supporting role. At midnight on 30 April the new high-speed main trunk complex of Washington–Bracknell–Paris–Offenbach was declared fully operational for both data-transmission and analogue facsimile exchanges. This meant that the MTC segment Washington–Bracknell had become the primary route for all exchanges of basic meteorological information between North America and Europe, and Bracknell was now the 'gateway' centre between the two continents. The old medium-speed circuit routed via Germany was closed down.

Planning for enhancement of the Bracknell RTH automated complex

During 1972 work had proceeded on the next phase (Phase II) of telecommunication automation for the Bracknell RTH. It became quite clear, however, that the contractor was unlikely to deliver Phase II before 1974, and therefore action would be needed to enhance the existing Phase I system in order to meet national and international commitments. Action was taken by the Telecommunications Branch to produce an outline technical specification or 'user requirement' describing why an enhancement was necessary, the additional facilities to be provided and also preferred ways of doing the job. After consultations regarding procurement action in January 1973 the Meteorological Office formally asked the MOD Procurement Executive (PE) to go ahead with the enhancement project. By April there were indications that the procurement procedure recommended by MOD(PE) was going to take much longer than envisaged by the Meteorological Office and there were suggestions of higher costs than originally reckoned. The outcome was a policy meeting at Directorate level, when it was accepted that the MOD(PE) proposals should be followed. These were that first a number of firms with relevant experience and competence in either the telecommunication or computer fields should be selected to study the official user requirement and tender for a paid project definition study (PDS). It was assumed that the PDS would take about 6

months, and the outcome was to be a comprehensive technical specification for the enhancement and a tender for a production contract to do the job.

By July all the evidence indicated that procurement of the enhancement was just not possible within the required 12-month period. Rather it seemed that delivery would take about 2–3 years from the start of procurement action; delivery in 1975 or 1976 seemed inescapable. Further consideration therefore indicated that for sound and effective planning, advantage should be taken of this long lead time to enhance the Bracknell automated complex on a scale adequate to meet the facilities and services likely to be required by 1975–76. Additionally there remained the urgent need to provide a high-speed electronic interface between the RTH automated complex and the computing laboratory 360/195 installation, and an outstanding commitment to provide data speed connections to the national meteorological centres (NMCs) at Oslo and Brussels during 1973.

The only sensible course was to provide an interim enhancement within the 1973–74 period, sufficient to meet the local interface requirement plus one connection to a European NMC; the latter was agreed to be Oslo initially. This interim enhancement had to be low cost and short lead time if it was going to plug the gap until the major enhancement was available. The Telecommunications Branch automation planning team concentrated on a mini-computer approach and it was decided to lease an IBM System 7 (assumed for 2 years), with an expected delivery about June 1974, the necessary additional software requirements being met by effort within the Office.

Invitations to the firms selected to tender for the PDS for the major enhancement (time-scale now indicating quite clearly it would be associated with the Phase II system) were sent out in August. Replies were required by October, and arrangements were made for each firm to make during November a one-day presentation of its proposals to representatives of the Meteorological Office and MOD(PE). Finally the firms were reduced to two, and these were awarded a contract to start a project definition study in January 1974.

Progress towards the new European Meteorological Telecommunication Network

The new European Meteorological Telecommunication Network (EMTN) is a part of the WWW plan for the GTS, and therefore it is intended to comprise automated telecommunication centres and medium- or high-speed interconnecting circuits. The major centres, such as Bracknell, are RTHs and the others are national centres. As shown in Figure 4, part of the MTC is routed through the middle of Europe via the on-trunk RTHs of Bracknell, Paris, Offenbach, Prague and the Moscow World Meteorological Centre (WMC). The Bracknell RTH, as in the case of its on-trunk counterpart centres, has a planned responsibility for, among other things, an input to the MTC of observational reports from designated areas including the U.K., Ireland, Iceland, Greenland and the Netherlands; also for the extraction of information from the main trunk and relay to the NMCs over regional circuits. The diagram is not intended to illustrate the configuration of the EMTN in full detail; its main purpose is to show the position of the Bracknell RTH in relation to the WMCs of Washington and Moscow, the other eight RTHs in Europe and the NMCs which are planned to be connected to Bracknell.

As already indicated, the MTC segments and also the main regional connection to Offenbach have been implemented. Regional connections to the

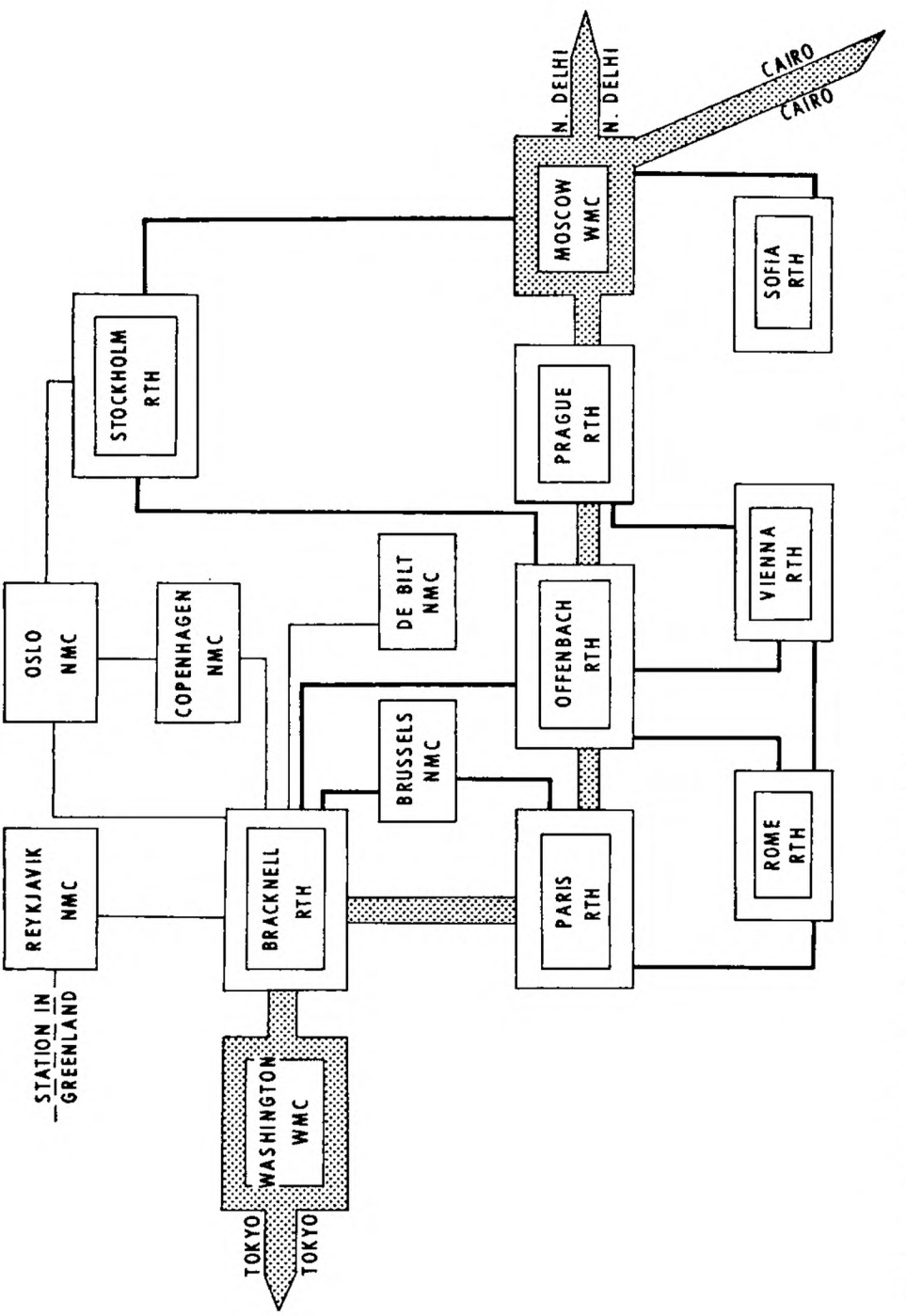


FIGURE 4—PART OF THE EUROPEAN METEOROLOGICAL TELECOMMUNICATION NETWORK

NMCs can only be implemented as the necessary facilities become available through a period of time as the Phase II system is commissioned, followed by the interim enhancement and then the main enhancement. But things have not been left completely in suspension. In consultation with our dependent NMCs certain temporary measures have been taken, or have been planned. For example, and as mentioned in last year's *Annual Report*, the EMTN connection with Oslo was anticipated in November 1972 by connecting four teleprinter circuits between Bracknell and Oslo; in aggregate this made effectively a 200-baud link, whereas the final EMTN connection will be at 1200 bauds. In September the Bracknell–Brussels connection was introduced, but for the time being only by means of a 50-baud teleprinter link. This has at least provided the means to supply the Belgian NMC with the specially requested output products in grid code from the Bracknell Regional Meteorological Centre (RMC). A similar low-speed arrangement has been made for the De Bilt (Netherlands) connection, mainly to supply information extracted from the MTC, as requested by the Dutch service. The next EMTN connection to be anticipated by a 50-baud link is the Bracknell–Reykjavik regional circuit; this is planned to be established on 1 January 1974. In the case of Copenhagen a direct facsimile circuit is already in service; possible future data exchanges have been discussed but only in general outline.

Planning for digitization of analogue transmissions

Within the United Kingdom and through international circuits the Meteorological Office uses analogue facsimile transmissions extensively. Technological developments and the increasing use of computers for telecommunication and data-processing purposes are pointing to the need for meteorological information to be transmitted in digital rather than analogue form. To take the equivalent of a normal facsimile map and digitize it in quanta related to a standardized facsimile transmitter, the digitized version if transmitted at 2400 bits/s (normal MTC data rate) would take about three times longer to transmit than for the analogue case. It is therefore necessary to produce fewer quanta by compression coding; tests by some services have shown that this can be done successfully with a gain in favour of digitization of around 4 to 1. Unfortunately some of this gain is lost when the digitized version has to be transmitted over an operational circuit employing GTS software error control, because this method is alphabet-conscious in terms of International Alphabet No. 5.

Although the Office has not been able to mount the desired effort in terms of laboratory developments and field trials concerning compression coded digital facsimile, it has played a leading role in World Meteorological Organization study-group work and consultation by correspondence. At the Sixth Session of the Commission for Basic Systems Working Group on the GTS held in Geneva in October/November, the subject was discussed with a view to setting down proposed technical characteristics and procedures, but this object was not achieved. This was mainly due to a serious lack of real experience with coded digital facsimile transmissions. In an endeavour to make good this deficiency, agreement was reached between the representatives of the MTCs of Tokyo, Washington, Bracknell, Paris and Offenbach that, as early as practicable, trials would be started between them.

Another area where coded digital facsimile transmissions are planned to be used is the military 'Skynet' satellite system. This system is already based on digital transmissions, so analogue facsimile is ruled out anyway. Planning action, and procurement for some conversion equipment, has been taken with the aim of providing a reliable service through 'Skynet' for transmitting pictorial information between, for example, Bracknell and the Episkopi (Cyprus) office. The present use of high-frequency radio broadcasts for this purpose is not entirely satisfactory.

Satellite services—pictorial readout facilities

The New Year saw the American ESSA 8 weather satellite entering its fifth year of continuous service and the new NOAA 2 weather satellite in operation. The ESSA 8 satellite uses the APT readout facility with which we have become very familiar, both in reception and usage of the cloud pictures. The NOAA 2 satellite uses scanning radiometer (SR) techniques for both infra-red and visible pictures. The SR system causes a severely distorted picture to be received at the earth station because of the geometry of the SR sweep and the curvature of the earth. After the APT pictures of conventional square shape and appearance, the SR pictures, seen as distorted strips, were not very popular with the operational forecaster.

A means of stretching the picture to enlarge it along the scanning lines was available from a British manufacturer, and as an interim solution equipment was ordered. The desired solution was of course removal of the distortion by proper linearization. Fortunately two research scientists at Dundee University had been working towards finding a solution of this problem, and they developed an electronic linearizer. Joint consultation between these Dundee scientists and Telecommunications Branch engineers led to a development project with a small electronics firm in Perth. Later in the year this firm produced a prototype linearizer, to a jointly agreed specification, in the shape of an 'add-on black box' which could be used in conjunction with the facsimile recorders already in service for satellite pictorial readout purposes. The prototype unit was acquired by Bracknell for evaluation from a number of aspects. The feedback arising from this evaluation will lead to the production model which will be commercially available.

In November the United States launched the ITOS-F/NOAA 3 weather satellite. This uses the same SR system as NOAA 2 and so the need for a picture linearizer is therefore increased.

Improvements to basic telecommunication facilities

Despite the efforts directed to the development of coded digital facsimile, the expectation is that analogue facsimile will still have a significant role to play, especially in our national services, for several more years. It was therefore decided in 1972 that we should embark on a major replacement scheme, starting with the older facsimile recorders which had been in service around 10 years or more. These had become troublesome in service and increasingly costly in terms of necessary replacement spares. The first pre-production model of the new replacement recorder was delivered to Bracknell in January 1973. The intention was to use this machine to obtain further technical appreciation of the many changes made and to determine what other changes might be needed. The next stage agreed with the firm was that we would take about 10 of the replacement

machines and subject them to a field trials programme, placing the new machines at selected offices for evaluation. The first batch of machines for the trials programme was delivered in March. From then onwards the programme ran into repeated difficulties; even after several months of investigation and discussion the new recorders failed to satisfy the Branch and the replacement programme has thereby suffered a setback.

For many years the teleprinter services of the Meteorological Office have been based on the Post Office Type 7 teleprinter and its associated equipment. Because the Post Office itself decided it was time to have something more modern, and introduced the Type 15 teleprinter, and because we must change the U.K. teleprinter networks to take full advantage of the Phase II automated system centred on Bracknell, a major replacement programme has been launched. The Type 15 has several advantages over the Type 7, but perhaps the more obvious are the built-in tape punch and tape reader. Provision of Type 15 machines is being made to all of the U.K. outstation offices which need to transmit observational data; by taking advantage of the tape facilities it is hoped to provide a ready means whereby reports can be taped and checked as error-free before starting transmission.

The proposal to build new ocean weather ships has presented both a challenge and an opportunity to the telecommunication staff. Acting as advisers to the Marine Superintendent on telecommunication aspects, the engineering staff have been involved in much investigation work with maritime bodies and firms with special expertise in the maritime communication field. As a policy decision, the main ship–shore communication system for meteorological reporting will be based on printing telegraph techniques. Arrangements are in hand to carry out field trials of one or two known radio-teleprinter systems before a final decision is reached. Despite the obvious temptation to go for the newest technological developments, it has been decided to be a little cautious and select a system which is modern in concept, has a good potential life ahead of it, but has at least seen some operational service.

Telecommunication international aspects

At various times and places throughout the year the telecommunication staff have been involved in an advisory role concerning projects of the WMO Voluntary Assistance Programme (VAP). Frequently those in the countries that are asking for equipment in order to fulfil their role in WWW do not have the appropriate knowledge to assess their needs in proper technical terms. It is therefore necessary to make an assessment of the true requirement and recommend the correct equipment. This has led to a significant amount of time being devoted to investigation work and deliberations with firms likely to supply the equipment.

The International Scientific and Management Group (ISMG) dealing with the GARP Atlantic Tropical Experiment (GATE) is located at Bracknell. Perhaps partially because of this, and certainly for other reasons too, Telecommunications Branch staff have from time to time been involved in the telecommunication planning for GATE. The planning has covered not only use of parts of the GTS, but also ship–shore and air–ground communications.

Slightly fewer visits overseas were made by the telecommunication staff during the year than in 1972, but nevertheless seven different countries

(including Iceland) were visited for meetings, problem-solving sessions or co-ordination of services. The Iceland visit was a combination of VAP assistance and bilateral consultation between an RTH and its associated NMC regarding system design and future compatibility of operation in an automated environment. As defined by the International Telecommunication Union, telecommunication concerns the transmission and reception of intelligence of any nature by wire, radio and other electromagnetic means. Communication can be defined as imparting information. To achieve either of these it is essential that the ways and means exist for passing information, and also that there is compatibility for information transfer. Without the necessary consultation, co-ordination and agreement between representatives of national meteorological services regarding the telecommunication systems and services now in existence, the smooth exchange of meteorological information experienced today on a global basis would not be possible.

International and Planning

The development of meteorology and its applications continues on a broad front, internationally as much as nationally. International co-operation is indispensable for daily operations in many fields and there is a need to share experience for mutual benefit. The World Weather Watch (WWW) of the World Meteorological Organization (WMO) comprises the basic system for observation, collection, storage and distribution of data for all general service purposes; and the Global Atmospheric Research Programme (GARP) organizes a comprehensive attack on the main large-scale problems of meteorology. There are many other research problems, and specialized arrangements for specialized services, besides these major programmes. While most of this work is associated with WMO, there are significant meteorological programmes associated with the International Civil Aviation Organization, the North Atlantic Treaty Organization and in the field of European co-operation, and several Specialized Agencies of the United Nations have meteorological elements in their programmes. One of the main functions of the Branch is to handle these general international matters, largely as a co-ordinator and as a channel of communications.

The recent greatly increased interest in ocean affairs, in which the Intergovernmental Oceanographic Commission (IOC) plays a leading role, has brought meteorologists and oceanographers into close collaboration. Besides joint activity on research projects in GARP this has led to the Integrated Global Ocean Stations System (IGOSS) of IOC being developed in association with WWW. Likewise the International Hydrological Decade, in which Unesco has played a leading role with extensive support by WMO and which ends in 1974, will be followed by an agreed long-term programme of co-operation in hydrology between the two organizations. The inclusion of operational hydrology within WMO's programme has resulted in the increased involvement in WMO of national hydrological services which in most countries are distinct from the meteorological service. In the United Kingdom this has involved mainly the Water Resources Board (WRB) and the Institute of Hydrology, and the Director of the WRB has designated a member of his staff as adviser on operational hydrology to the Permanent Representative. The meetings listed in the section 'International Co-operation' summarize the external aspects of this work.

The development of WWW and to a lesser extent of GARP has led to a much closer integration of the work of the different bodies in WMO and related activities elsewhere. As a result national preparations for meetings of these bodies increasingly require close co-operation between many parts of the Office and with other institutions to ensure the co-ordination of policies and their implementation.

Close working relations were maintained throughout the year with the Director and staff of the International Scientific Management Group for the GARP Atlantic Tropical Experiment, located in Bracknell, in detailing the plans for the Experiment and the U.K. part in it. Two scientists were seconded to work with the Group for most of the year, and a number of other staff took part in various informal groups.

The facilities of the Meteorological Office College at Shinfield Park were used in May for a WMO scientific symposium on a special topic in numerical weather prediction. The symposium was organized by staff of the Office including the College. The maximum capacity of the lecture theatre set a limit to the number of visiting participants, who were nearly all accommodated in the College. The arrangements were found very suitable. The College facilities were also used for sessions of two international working groups.

The U.K. offer of a site in the College grounds for the European Centre for Medium Range Weather Forecasts was accepted, and the Convention concerning the Centre was signed in October by 15 European countries. Until a permanent building for it can be designed and erected, the Centre will be set up in temporary accommodation being provided by the U.K. in a new office building in Bracknell. This accommodation was furnished ready for occupation by the Centre's interim Director and his staff, expected early in 1974.

Contact on WMO matters relevant to them was maintained with those dependencies of the U.K. represented in WMO by the Permanent Representative. There was much consultation with the meteorological service of the Seychelles both in preparation for the August session of the Regional Association for Africa and over the plans for the new upper-air station for WWW to be set up at Mahé, Seychelles. The plan for its establishment was agreed with the Seychelles Government, but some difficulties appeared later in the year over the site selected.

The plan for another new upper-air station on St Helena was drafted and despatched for the consideration of the Governor. The upper-air station at Tarawa in the Gilbert Islands (see Plate VII, lower) was completed and came into operation in November, with much help from the meteorological services of Australia and New Zealand. The latter operates the station as agent of the United Kingdom. The station at Funafuti, run in a similar way, resumed operation after its destruction by a storm in 1972. Joint support by the United Kingdom and France of the upper-air station at Vila in the New Hebrides continued. Plans were developed for increasing the number of surface observations made on St Helena and by the Royal Society Expedition on Aldabra, Indian Ocean.

Action to help other countries implement WWW requirements on their territories continued, mostly through the Voluntary Assistance Programme of WMO. Four new fellowships for university-level meteorological education in the U.K. were awarded, five were continued for a further year at least, and six fellows completed their courses. Telecommunication equipment for collecting

or exchanging data was given to Jordan and Nigeria and offered to British Honduras, Czechoslovakia, the East African Community, Nigeria (second phase), Senegal and Sierra Leone. Preliminary discussions on similar offers were begun with Argentina and Somalia. Offers of wind-finding radars were made to and accepted by Guinea, Mauritania, Niger and Sudan, as part of a joint operation by several donor countries. These sets will, it is hoped, be in operation in time for the GARP Atlantic Tropical Experiment in mid 1974. Preliminary discussions began with Mauritius about a radar for use on St Brandon Island, and instruments for a surface station were offered to the Maldive Islands. A further cash contribution was also made to the central fund of VAP which is used to meet urgent requests not likely to be met directly by donor countries.

As regards accommodation planning for the Office, a study was made of requirements over the next 10 years or so, and some ways of meeting them on the Office's existing sites in Bracknell.

J. K. BANNON
Director of Services

SUMMARY OF THE WEATHER OF THE YEAR (1973)

The first three months were mostly mild and rainfall was continuously below average in many areas, being less than half of average in most eastern districts. During the rest of the year temperatures were mostly near average although April, October and November were rather cold. Rainfall in eastern Scotland was a little above average in April and May but during the following six months it was continuously below average. In other districts rainfall was variable from April onwards, but August was a dry month in the east and October was very dry generally.

January. An anticyclone dominated the weather over the United Kingdom for most of the first half of the month maintaining easterly or north-easterly winds over eastern and southern areas and south to south-westerly winds in the west and north. In Scotland, Northern Ireland and northern England there were strong to gale force winds and changeable weather at first but after the 4th low cloud, fog and occasional rain or drizzle which had until then affected only Wales and parts of England spread to most other districts as the anticyclone intensified. In the south-eastern half of England and Wales foggy areas were sometimes very cold with moderate or severe night frosts but elsewhere it was much milder and some exceptionally high temperatures were recorded for early January. On the 1st a maximum temperature of 16·0°C was measured at West Kirby Park (Cheshire). From the 15th to 31st a succession of low-pressure systems alternating with ridges of high pressure affected the country. Winds were frequently strong, especially in the north and north-west, reaching gale force locally and rainfall was heavy at times with occasional hail and thunder. Many places reported a little snow or sleet* but the areas chiefly

* Rain or drizzle and snow.

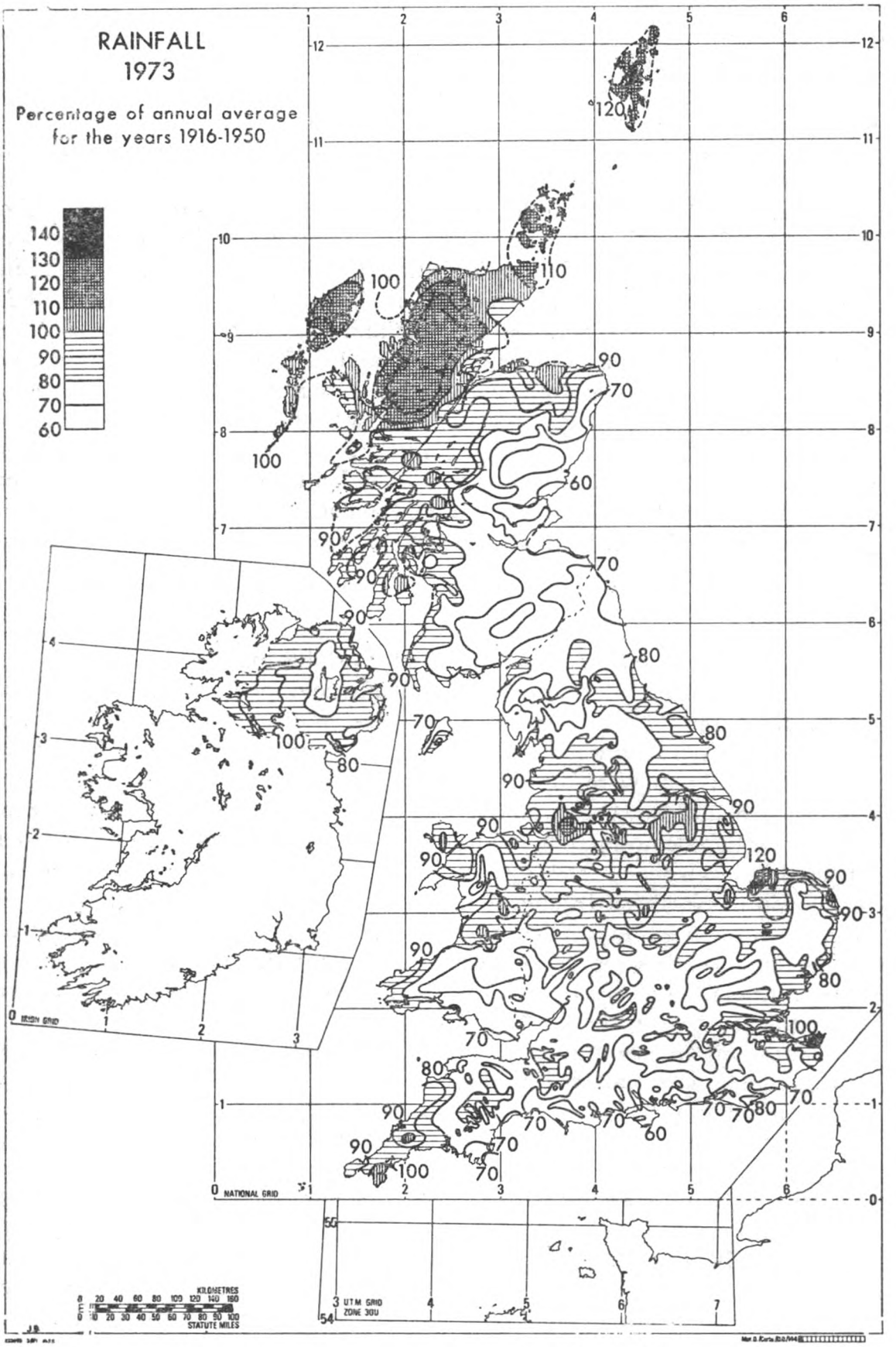


FIGURE 5—RAINFALL 1973

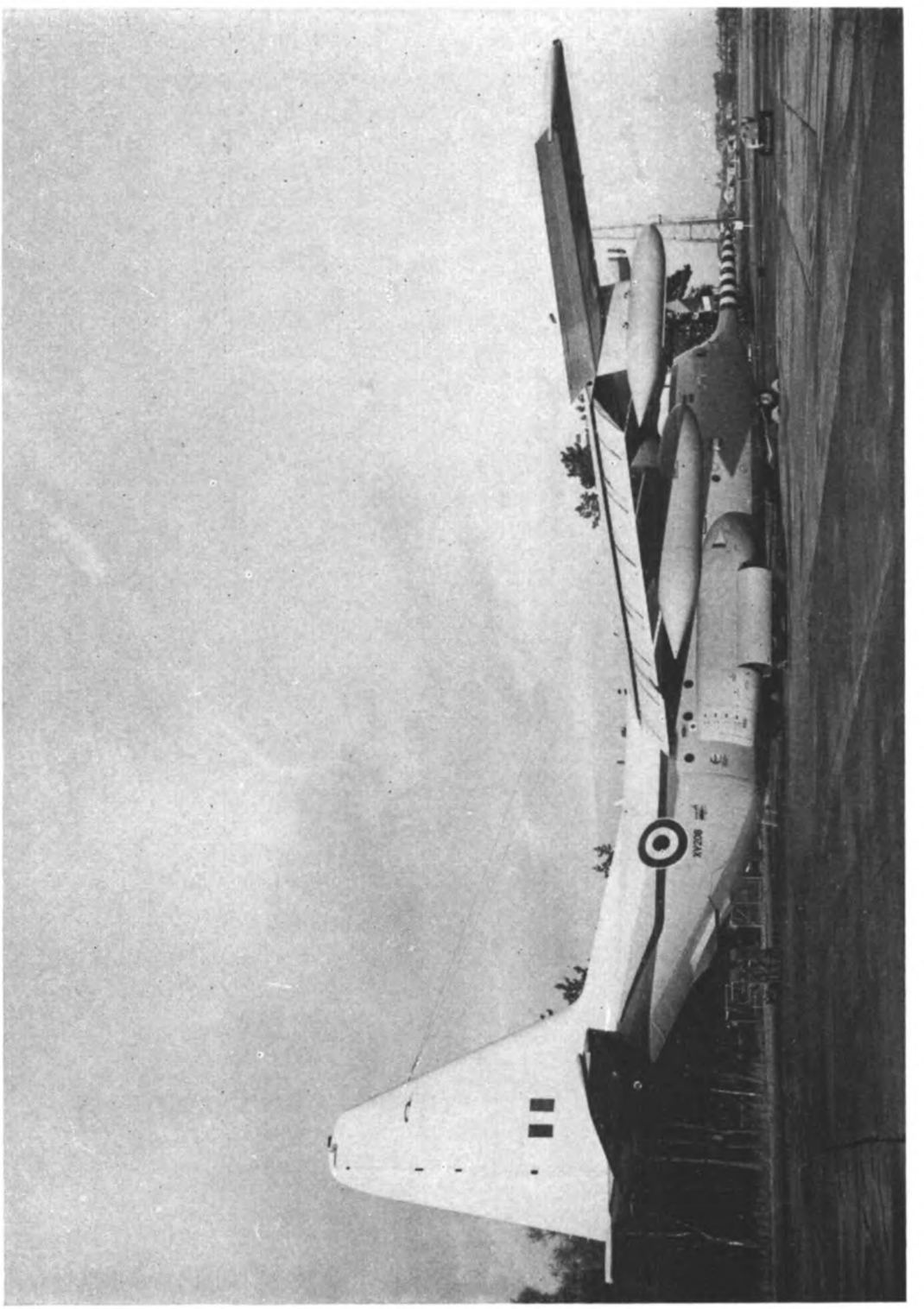
affected were in the west and north. During severe gales in western districts on the 15th, gusts of 74 knots and 75 knots were measured at Belfast Harbour and at Machrihanish (Argyll) respectively. On the 17th and 18th quieter weather prevailed with night frost and extensive and persistent fog in many districts but winds increased again during the next few days and there were severe gales on exposed western and northern coasts. Rainfall amounts (including melted snow) were large in places especially in Northern Ireland where one or two falls classified as 'remarkable' occurred. In the 24 hours from 09 GMT on the 19th, 114·6 mm fell at Castle Wellan and 100·8 mm fell at Timtany, both in County Down. The period from the 19th to 22nd was cold in many areas and snowfall was extensive over high ground in Wales, in western and northern England and in southern and western Scotland. Undrifted depths of 25 cm or more were measured in a number of places and drifts blocked mountain roads temporarily. Showers, often of snow or hail, were also widespread in the south and south-west and on the 21st a waterspout was observed off the Sussex coast near Newhaven. Changeable weather continued for the remainder of the month but it was mostly mild until the last day when it turned colder. For the month as a whole, although sunshine was notably deficient, mean temperatures were generally above average. Rainfall was close to the normal in Northern Ireland but elsewhere it was dry.

February. The unsettled weather which had begun around mid January continued throughout February. Mild spells and cold spells followed one another rapidly and monthly mean temperatures were mostly near average. Sunshine amounts were near or above average despite the unsettled conditions and England and Wales were again much drier than average. In Scotland and Northern Ireland, however, rainfall was close to average. At first, occasional light rain or drizzle and patches of hill fog affected northern and north-western districts but elsewhere it was mostly dry and fog and frost were widespread. Heavy rain in Northern Ireland and Scotland from the 4th to 6th included a 24-hour fall of 66·4 mm at Glenfinnan (Inverness-shire) on the 5th and strong to gale force winds gave gusts exceeding 60 knots in parts of Scotland and northern England on the 6th and 7th. During the next few days wintry showers frequently occurred in the north and west with hail and thunder at times and snow on the higher ground but precipitation in other areas was mostly of rain and was much more scattered. Wales and north-west England had particularly heavy rainfall on the 11th and subsequently colder air penetrated to all districts with snowfall reaching as far south as Cornwall. Severe gales and heavy snow occurred in Northern Ireland, Scotland and northern England as an intense depression crossed northern areas during the night of the 12th/13th. Winds reached storm force (mean speeds of 48 to 55 knots) in places and Tiree (Argyll) had a gust of 70 knots. There was considerable drifting of the snow and mountain roads were blocked for a time. Prolonged snowfall also occurred in southern England on the 14th and in south-west England, north-west Scotland and Northern Ireland on the 15th. During the night of the 14th/15th moderate to severe frost was widespread and patches of freezing fog developed in England and southern Scotland. At Carnwath (Lanarkshire) the temperature fell to −21°C, the lowest February temperature there since records began in 1953. The next three days were mostly dry, cold and sunny with extensive fog and

PHOTOGRAPH TAKEN DURING INSPECTION OF THE HERCULES AIRCRAFT

Standing near the nose probe, from left to right: Mr J. S. Sawyer, Dr R. Frith, Dr B. J. Mason, Mr R. F. Jones, Mr D. G. James and Mr J. F. Fisher. (See page v.)

PLATE II



HERCULES AIRCRAFT SHORTLY AFTER DELIVERY TO THE METEOROLOGICAL RESEARCH FLIGHT

See page v.

HERCULES AIRCRAFT OF THE METEOROLOGICAL RESEARCH FLIGHT

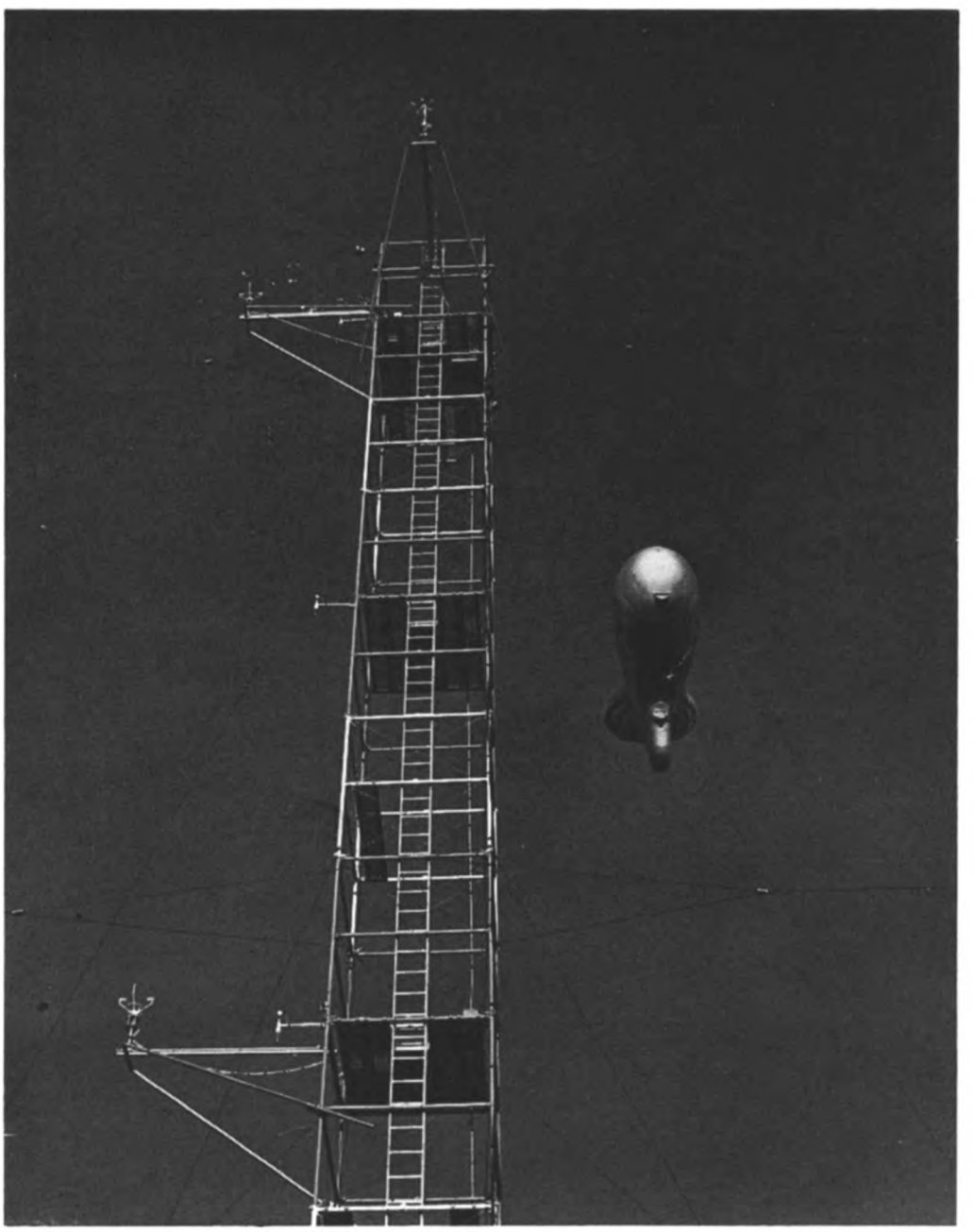
See page v.

PLATE IV

Photograph by courtesy of AFCRL, Bedford, Mass.

RADIO-RECEIVING AERIAL BEING DIRECTED AT A TURBULENCE MEASURING SENSOR

The sensor was carried on the tethering cable of the balloon as part of the boundary-layer study carried out in Minnesota in September 1973, jointly with scientists of the U.S. Air Force Cambridge Research Laboratories. (See page 86.)



Photograph by courtesy of AFCRL, Bedford, Mass.

THE TOWER INSTRUMENTED BY AIR FORCE CAMBRIDGE LABORATORIES FOR THE JOINT BOUNDARY-LAYER STUDY IN MINNESOTA

Sonic anemometers, which can be seen on the two large booms, provide measurements of the three components of turbulence at heights of 4 m and 32 m. Shielded aspirated quartz thermometers are mounted on the smaller booms. The tethered balloon carries the Cardington Research Unit's turbulence sensors at five levels up to about 1 km. (See page 86.)

PLATE VI

Photograph by courtesy of Centre Spatial Guyanais, Kourou.

JOINT INTERNATIONAL TRIAL OF ROCKET SOUNDINGS AT KOUROU, FRENCH GUIANA IN SEPTEMBER 1973

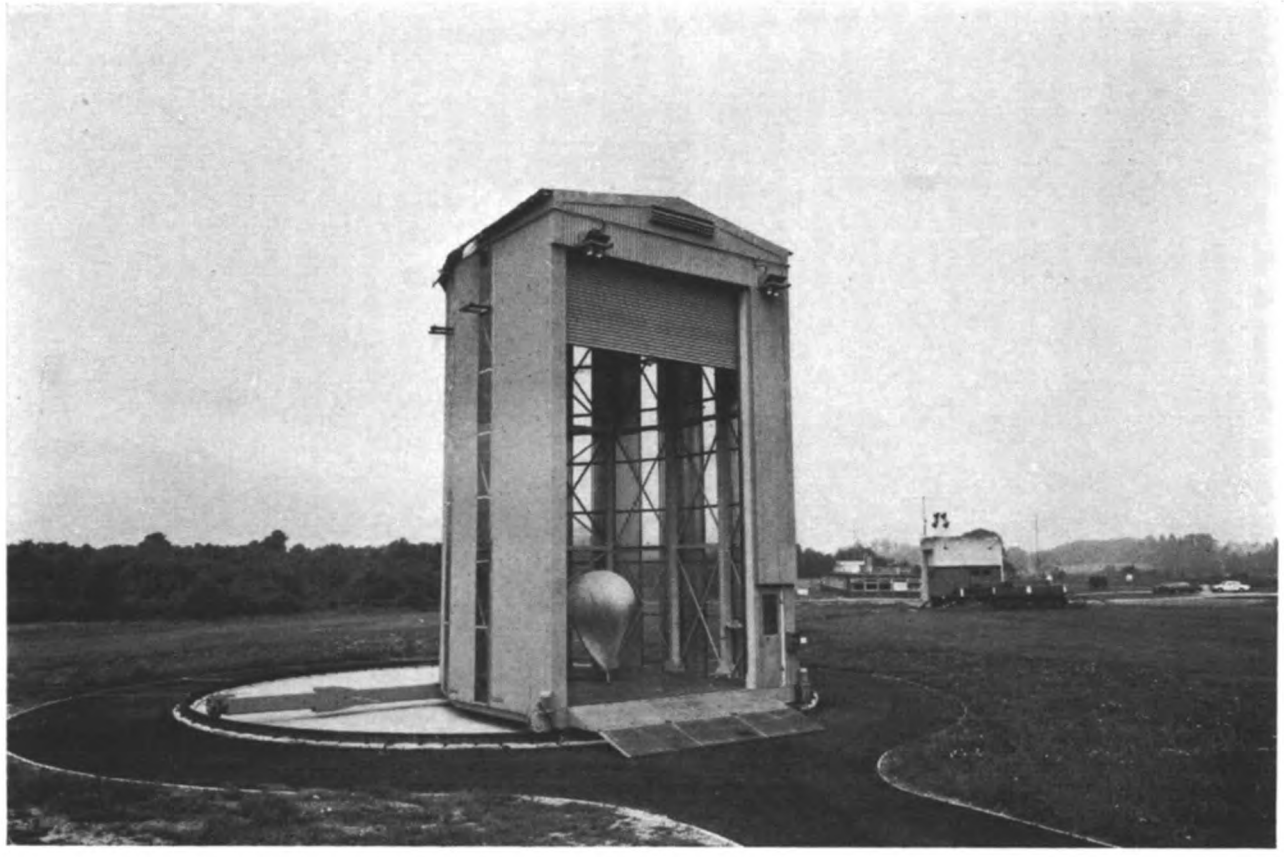
The U.K. team with its launcher. Other teams were from France, the United States and the U.S.S.R. (See page v.)

Photograph by courtesy of Centre Spatial Guyanais, Kourou.

JOINT INTERNATIONAL TRIAL AT KOUROU, FRENCH GUIANA
Loading a SKUA rocket. (See page .v)

Photograph by Mr G. Needham.

WIND-FINDING RADAR OF THE NEW WORLD WEATHER WATCH UPPER-AIR STATION AT TARAWA, GILBERT ISLANDS, OPENED IN NOVEMBER 1973
See page v.



Photograph by courtesy of the Department of the Environment.

PROTOTYPE ROTATABLE BALLOON-FILLING SHELTER AT BEAUFORT PARK

The photograph shows the aerodynamically-shaped shelter (internal height 9 m, width 5·5 m) which can be turned to enable large balloons to be launched down-wind, even in strong winds (see page 45).

frost at night but it was warmer thereafter especially in some eastern areas. On the 20th, a maximum temperature of 16·6°C was recorded at Aberdeen, the highest February temperature there for at least 23 years. The 20th to 23rd was a windy period with local gales in exposed places and colder weather with frequent wintry showers and occasional hail and thunder affected most districts during the following days. On the 25th there were outbreaks of freezing rain in parts of the south and west. Frost was widespread and locally severe and there were patches of freezing fog which were slow to clear in one or two places. Towards the end of the month rain spread from the north-west and it became generally mild once more.

March. In general this month was sunnier and much drier than average and warmer too except in Northern Ireland where the mean temperature was close to normal. Changeable weather occurred throughout the first week and on one or two days there were prolonged snow showers. Undrifted depths of 5–10 cm of snow were measured in parts of Scotland and in the northern Pennines but it did not lie for very long. The 6th was squally especially in the Midlands and southern England where gusts exceeding 50 knots were recorded. During the 2nd and 3rd weeks unsettled weather continued in the far north but it was mostly dry elsewhere with some warm sunny days especially in eastern and southern areas. Frost was occasionally severe in Scotland and on the night of the 10th/11th the temperature fell to −13·5°C at Buddon Ness (Angus), the lowest March temperature measured there since records began in 1941. Patches of fog, some of it freezing, often developed at night and were sometimes dense and slow to disperse; in Belfast the fog persisted all day on the 11th. Between the 21st and 23rd outbreaks of rain or showers returned to most districts although it remained mostly dry and rather warm in the east. Day-time temperatures rose to 16°C or over in a number of places and on the 23rd a maximum temperature of 19·4°C was recorded at East Dereham (Norfolk). During the last week gales occurred frequently in Northern Ireland and Scotland and there were outbreaks of heavy rain, some thunder and hail and snow on high ground. Among the noteworthy 24-hour rainfall amounts (which include melted snow) on the 29th were: 65·0 mm at Broadford and 56·5 mm at Glenfinnan, both in Inverness-shire. On the same day a gust of 60 knots was recorded at Stornoway (Ross and Cromarty) and on the 31st the wind at Duirinish (Ross and Cromarty) gusted to 61 knots. Depths of 8 cm of undrifted snow were measured in parts of the north-west Highlands. The last week was much quieter and drier in districts farther south with frost and fog at night and long sunny periods by day.

April. The weather was generally changeable and cool but sunshine was about normal and in Great Britain taken as a whole, rainfall was also close to average. Northern Ireland was a little drier than usual. The month started very windy with frequent gales around the coasts and in exposed inland areas. Rainfall was often heavy especially in the west and the north and on the 1st 85·4 mm of rain fell in 24 hours at Moel Cynnedd (Montgomeryshire). Snow fell on high ground at times and there was a little hail and thunder. Gusts of 60 knots or more occurred in the Midlands, eastern and southern England

during widespread gales on the 2nd. Three people were killed, trees were blown down and property damage was also reported. On the same day heavy snow fell in the north and north-west and undrifted depths of between 9 and 18 cm were measured in the mountains of northern England and southern Scotland where some roads were temporarily blocked. Further damage occurred when severe gales swept north-west England and south-west Scotland on the 4th. Two days later a gust of 70 knots was recorded at Stornoway (Ross and Cromarty). Snow fell in many central and southern districts of England and Wales on the 8th and 9th and settled for a time. Depths of about 4 cm were measured on low ground and 8–12 cm accumulated in places on higher ground. For most of the next two weeks rainfall was small. Winds were light or moderate except on some eastern and northern coasts where they reached gale force occasionally. During this period the days were sunny and warm in many areas and at Buddon Ness (Angus) a maximum temperature of 19·2°C was measured on the 15th. However, the nights were cold with frost and fog in places. From the 21st onwards rainfall became heavier and more widespread especially in the west and north. Hail and thunder occurred at times and snow or sleet fell on hills. Winds continued mostly light or moderate in central and southern areas but in the north and north-west they were frequently fresh or strong and occasionally reached gale force in exposed places. On the 27th and 28th there was heavy snow with considerable drifting in northern Scotland and undrifted depths of 10–15 cm were measured in Shetland. On the following night the temperature fell to −9·9°C at Eskdalemuir (Dumfriesshire) the lowest temperature recorded there in April since 1917. In Northern Ireland severe frost caused widespread damage to the apple crop in Armagh and to other crops throughout the Province.

May. This was the first month of 1973 which was generally wetter than average. England and Wales had only a little less sunshine than usual and the mean temperature was near average. In contrast, Northern Ireland and Scotland were both rather cool and dull. The first half of the month was cool generally with heavy rain and thunder at times and winds were frequently fresh or strong with occasional gales. Snow fell on one or two days in Northern Ireland, Scotland and northern England on the 1st; 4–8 cm were measured on low ground in north-east Scotland and 15–23 cm in the mountains. On the same day a minimum temperature of −7·6°C was measured at Carnwath (Lanarkshire), the lowest May temperature there since records began in 1952. In the 24 hours from 09 GMT on the 3rd, 66·0 mm of rain fell at Pubble Forest, County Fermanagh and rain was also heavy in many other districts on the 3rd and 4th. It was reported that rooms in both Houses of Parliament were flooded for a time on the 3rd after a particularly heavy downpour in London. It was windy too. Gusts of 55 knots or more were reported from a number of coastal stations in Wales and south-west England on the 4th. Widespread rain on the 9th produced some heavy falls in the west and 76·2 mm of rain fell at Honister Pass (Cumberland) but on the 12th heavy rainfall was confined almost entirely to Northern Ireland and Scotland. On the 10th a gust of 65 knots was reported from Belfast Harbour during gales which occurred widely in Northern Ireland and Scotland. For a few days around mid month it was sunny in many districts but there was frost and patchy fog by night and temperatures remained mostly

near or below average. On the 17th strong to gale force easterly winds in many areas and heavy rain in the south-west heralded the return of unsettled weather which lasted throughout the rest of the month. Temperatures rose generally and remained above average in most areas. Rain or showers were frequent with thunderstorms and hail at times and some hill fog. Short-lived patches of fog often occurred on lower ground overnight and many coastal areas were affected by sea fog. On the 21st a 24-hour fall of 52·1 mm of rain was measured at Woburn (Bedfordshire) and on the 28th a policeman was injured by lightning near Andover (Hampshire). Some of the higher temperatures of the month occurred at inland stations during the last week and among these was a maximum temperature of 25·8°C at Hampstead (Greater London) on the 27th.

June. Temperatures were generally above average this month and in England and Wales it was sunny in spite of outbreaks of heavy thundery rain which largely contributed to the overall excess of rainfall. Scotland was rather dull with near average rainfall but Northern Ireland was very dry and sunshine was about average. During the first 3 days rain and showers in many areas were occasionally moderate to heavy with a little hail and thunder. From the 4th to 8th it was mostly dry and there were hill and coast fog patches in the north and north-west. It also became very warm especially in the east and south. At Dundee (Angus) the temperature reached 28·7°C on the 6th, the highest temperature measured there in June since records began in 1915. Further rain occurred between the 9th and 12th and there were copious 24-hour falls in the west and north. Among these was one of 130·5 mm at Couldoran (Ross and Cromarty) on the 11th. This fall is classified as 'remarkable'. Winds were strong in the west and north and there were gales in exposed places. On the 12th a gust of 72 knots was recorded at Stornoway (Ross and Cromarty) and further gusts exceeding 50 knots were reported on the 13th. Except in the north the next few days were mostly dry and often warm and sunny. On the 16th maximum temperatures just exceeded 27°C in a number of places in the Midlands, east and south-east England. On the 19th rainfall became general and thunderstorms were widespread in east and south-east England. There were injuries and damage due to lightning and sudden floods resulted from intense rainfall. Among some 'remarkable' falls was one of 63·0 mm in 4 hours 25 minutes at Chessington (Surrey). On the 20th local gales occurred in northern, western and central areas of England and Wales and rain continued in the east but died out during the following night. Scattered thundery showers occurred in the west and north during the next few days but widespread thunderstorms developed in the south and east on the 24th and again on the 26th and 27th. On the 26th hailstones up to 2 cm in diameter fell near Bedford and two tornadoes passed over Cranfield (Bedfordshire). The second tornado completely destroyed the wind laboratory of the Electrical Research Association and later on the same day tornado damage was reported from the villages of Parson Drove and Tydd Saint Giles (both in Cambridgeshire) and from Tydd Saint Mary (Lincolnshire). The north and west became mostly dry on the 26th but rain returned on the 29th. Elsewhere the weather improved on the 27th and this improvement lasted until the end of the month. During the last two weeks patches of dawn fog occurred at times chiefly in the

Midlands, and eastern and southern England. Hill fog was extensive at times in the west and north and many coastal areas were affected by sea fog.

July. Temperatures and sunshine were near or below average generally and in Scotland and Northern Ireland it was drier than usual. In England and Wales, however, rainfall overall was once more above average. During the first week sea fog affected many coasts and in the north and north-west rainfall was frequent and sometimes heavy with thunder. Other districts were mostly dry and sunny for much of the time though with a few dawn fog patches. Days were very warm in eastern and southern areas and temperatures exceeded 25°C in some places. On the 5th a maximum temperature of 30°C was recorded at Mayflower Park, Southampton. On the same day thunderstorms broke out in the south and spread to the Midlands and eastern England on the 6th. Lightning injured two boys in Harrow and electricity supplies to Canvey Island (Essex) were cut off for a time. Among the intense falls of rain which resulted in sudden floods in some localities was one of 116·5 mm in 5¼ hours which was reported from Chessington (Surrey). This is classified as a 'very rare' fall. Following a short mostly dry period substantial rainfall returned to many areas between the 10th and 14th. Heavy outbreaks with local thunder occurred in the north and hill and coast fog was extensive in the north and west. During the next 3 days widespread heavy rain and thunderstorms affected the whole of England and Wales. Some thundery rain affected Northern Ireland and southern Scotland from time to time but farther north it was mostly dry and warm. Lightning damage and floods were reported from a number of places and a 'remarkable' fall of 137·4 mm in a 24-hour period from 09 GMT on the 15th was recorded at Rivelin (Yorkshire, West Riding). In northern England and Scotland easterly winds were fresh or strong with local gales and on the 16th a mean hourly wind speed of 60 knots and a gust of 74 knots were measured at the high-level station at Great Dun Fell (Westmorland). On the 17th a whirlwind which lifted a greenhouse was reported from Bognor Regis (Sussex) and two waterspouts were also observed in the same area. Except for a dry and mostly sunny period between the 26th and 28th most areas had periods of rain or showers during the rest of the month and thunderstorms were fairly frequent over England and Wales. Sea fog encroached on northern and eastern coasts of Scotland and on the north-east coast of England at times and there were patches of dawn fog in eastern and southern areas of England and Scotland. Two waterspouts were seen near Broadstairs on the 23rd and on the 26th a whirlwind about 40 feet in diameter passed over the beach at Canford Cliffs, Poole (Dorset).

August. Although it was again drier than average in Northern Ireland and Scotland, rainfall in England and Wales as a whole was below average for the first month since March. Sunshine and temperatures were generally near or a little above average. Early days of the month were wet and in the north and west also rather windy. Except in the north, England became mostly dry after the 7th but the drier weather was delayed until the 12th in other districts. Thunderstorms occurred at times, particularly over England and Wales and on the 1st a policeman was killed by lightning at Hartlepool (County Durham). On the same day during a thunderstorm over south-west London, lightning

damaged buildings and there was local flooding. A 'very rare' fall of 68·3 mm of rain in 45 minutes occurred at Balham. Further flooding was reported during widespread heavy rain on the 5th and 6th, and on the 7th a whirlwind associated with a thunderstorm near Southend (Essex) damaged houses and trees and lifted parked cars at Thorpe Bay. Gales occurred at times in exposed places and on the 9th a mean hourly wind speed of 60 knots and a gust of 80 knots was recorded at the high-level station at Cairngorm (Inverness-shire). From the 12th to 16th many districts had warm sunny weather with maximum temperatures reaching 32°C in places in the east and south. Rain and isolated thunderstorms in Northern Ireland and Scotland on the 16th marked the return of significant rainfall but outbreaks were scattered until the last week of the month when they became more frequent and widespread. Extensive flooding occurred in parts of south-west England and the Channel Islands during thunderstorms on the night of the 22nd/23rd and 76·0 mm of rain fell in about 7 hours at Dartmouth (Devon). On the 27th severe thunderstorms were widespread in the Midlands and southern England and heavy rain was reported in central and north-western Scotland on the 31st. Most inland areas had occasional fog patches around dawn and in the Midlands, eastern and southern England they occurred frequently throughout the month. Between the 12th and 24th and again on the 29th, sea fog affected eastern and southern coasts and hill fog occurred widely in heavy rain during the first and last weeks.

September. Rainfall was once again below average in Scotland and Northern Ireland but England and Wales were wetter than normal. Temperatures and sunshine were above average in England, Wales and Northern Ireland but a little below average in Scotland. The first 9 days were mostly very warm, particularly in eastern and southern districts where day-time temperatures often exceeded 25°C. On the 5th a maximum temperature of 31·0°C was recorded at Gillingham (Kent). Winds were fresh or strong at first and there were local gales over high ground and on exposed coasts in the west and north but later they were generally light or moderate. Rain or showers occurred at times, again mostly in the west and north, but falls were seldom heavy although one or two places in Wales had over 70 mm of rain in 24 hours on the 2nd. There were isolated thunderstorms in England and Wales during the night of the 4th/5th and again over south-eastern England on the 8th. Subsequently most districts became a little cooler but remained dry and often sunny. This weather continued until the 14th. During the first half of the month fog patches developed frequently at night and were occasionally slow to disperse. Hill fog occurred at times in the west and sea fog affected many coastal areas at one time or another. During the second half, fog was much less prevalent and the weather during the rest of the month was often stormy with frequent outbreaks of heavy rain or thunderstorms. Temperatures declined and it became rather cold towards the end of the month. On the 18th and 19th there were gales in many parts of England and Wales and they were particularly severe along the English Channel coasts where gusts of 60 knots and over were recorded. A depression moving across northern France to the southern North Sea gave exceptionally heavy thundery rain in some south-eastern areas on the 20th and 21st. There was considerable flooding and among the many copious falls recorded in Kent were 190·7 mm at West Stourmouth and 167·1 mm at Ashford. Both of these occurred in the 24 hours from 09 GMT on the 20th and

are classified as 'very rare' falls. Winds reached gale force in many places during the last 4 days with gusts of 60 knots or more on exposed coasts in the west and north. Outbreaks of heavy rain or showers were also widespread and 24-hour falls exceeding 50 mm were reported from a number of places in Wales, western Scotland and Northern Ireland.

October. The month was colder and much drier than average generally but it was quite sunny especially in northern and western Scotland where some places had their sunniest October for over 30 years. Mild weather predominated until the 9th with a little rain and drizzle at first and patches of sea fog in the north and west. Overnight fog occurred frequently in central and southern Scotland and in England and Wales. Heavy rain and thunderstorms spread into south-western districts on the 5th and affected much of England and Wales on the 6th and 7th. Among some intense falls was one of 40·9 mm in 35 minutes recorded at Taplow Court (Berkshire) on the 6th. This is classified as 'very rare'. Floods were reported from a number of places in southern England and lightning damage interrupted electricity supplies in parts of Sussex and Kent. From the 10th to 22nd temperatures were mostly below average and wintry showers of snow or sleet were reported at times in Northern Ireland, Scotland and in northern parts of England and Wales. Although depths of undrifted snow were generally small, 8–10 cm were measured at a few higher-level stations in northern Scotland between the 18th and 20th and snow lay for a few days on ground above 450 m. Night frosts occurred frequently and at Lagganlia (Inverness-shire) the temperature fell to −8·5°C on the 12th. Heavy rain in the south-west of England and Wales between the 11th and 14th included 'remarkable' 24-hour falls of 96·0 mm which were recorded both at Trengwainton House, Penzance (Cornwall) and at Trewidden (Cornwall). Easterly winds reached gale force at times in the same area on the 12th and 13th. During the third week winds often reached gale force in exposed places and on the 20th and 21st gusts exceeding 60 knots were reported in the Irish Sea area and along the north-east coast of England. After the 22nd temperatures were generally near average and the weather became more settled in England and Wales with scattered slight rain or drizzle only. In Scotland and Northern Ireland, however, the arrival of drier weather was delayed until the last few days. Patches of hill fog occurred in the north and west and fog developed frequently at night in central and southern Scotland and in many areas of England and Wales. Fog was particularly dense and persistent in the Midlands and eastern and southern England where surface and air transport was delayed for a time on the 29th and 30th.

November. England and Wales on the whole were much sunnier and drier though a little colder than average. Other areas were colder and wetter than average but, while Northern Ireland was rather dull, Scotland generally was a little sunnier than usual. From the 1st to 3rd the weather was a little milder than normal and light rain or drizzle fell in places. Fog occurred widely in the Midlands and southern England. Two weeks of colder, unsettled and windy weather ensued during which outbreaks of rain or showers were frequent and sometimes heavy especially in the north and west. Some of the showers were of hail and were sometimes accompanied by thunder. Snow or sleet fell at times

mostly on high ground in Scotland. On the 9th rainfall was particularly heavy in North Wales and some stations there recorded 24-hour falls exceeding 100 mm; Blaenau Ffestiniog (Merioneth) had 147·0 mm. On the following day there were Press reports of floods of up to 5 feet in depth in parts of Caernarvon when the River Cadnant overflowed its banks. Strong to gale force winds were experienced in many districts and gales were severe in Northern Ireland, Scotland and northern England on the 12th. Gales were again severe in Scotland on the 19th. On both of these occasions gusts exceeding 65 knots were recorded on exposed coasts and over high ground. Many districts enjoyed quieter and drier weather from the 20th to 23rd and there was a good deal of sunshine but in north and north-west Scotland fresh or strong winds continued and there were showers or periods of rain at times. Fog patches occurred frequently in England and Wales. Changeable, windy weather was renewed on the 24th and gales were widespread and severe at times in Northern Ireland, Scotland and northern England where gusts of 70 knots or more were reported from a number of stations. Two men were killed in Edinburgh during gales and Press reports spoke of widespread damage to property in Scotland and northern England on the 24th and 25th. After the 26th winds moderated slowly although they remained fresh or strong for a time in Wales and south-west England and there were gales on the coast of north-east England on the 29th. More snow fell during the last week and undrifted depths of 10 to 20 cm were measured in Scotland. Undrifted depths of 5 to 10 cm were measured in places in Yorkshire, in East Anglia, in parts of Wales and on Dartmoor (Devon). Night frost, which hitherto had not been a significant feature, occurred widely towards the end of the month and patches of presistent freezing fog were also reported. The frost was particularly severe in northern England and southern Scotland and at Carnwath (Lanarkshire) the temperature fell to −14·7°C on the night of the 28th/29th, the lowest November temperature there since records began in 1952.

December. Rainfall was again above average in Northern Ireland and Scotland and below average in England and Wales. Most districts were sunnier than usual but temperatures were generally not far from average. The cold weather which prevailed towards the end of November continued on the 1st and 2nd, particularly in parts of Scotland and northern England. Severe night frost occurred and there were patches of persistent freezing fog. By the 3rd, however, rain and drizzle had spread from the Atlantic to all areas preceded by snowfall on the mountains of Scotland and thereafter mild periods with outbreaks of rain alternated with colder spells during which there were wintry showers and occasional hail and thunder. Many places, especially in the south, also had bright or sunny intervals. Winds were often strong and gales occurred locally. The 12th to 14th was a particularly windy period and gusts exceeding 60 knots were recorded at places on the northern and eastern coasts of Great Britain. Further gales occurred in northern districts between the 16th and 18th. On the 19th rain spread across the United Kingdom from the south-west and turned to snow over Scotland. Falls were heavy in places both on low ground and at higher levels and undrifted depths of 20 cm or more were reported from a number of stations; a depth of 38 cm was measured at Glenmore Lodge (Inverness-shire). Intermittent rain or showers with occasional hail and thunder affected all areas from the 20th to 31st but it was mostly a little milder than

average and snow showers were confined to the extreme north of Scotland. There were a few sunny days and frosty nights, but the only notable occurrence of fog was on the 25th when it was widespread and persistent over much of England and Wales. Winds which were fresh or strong at times in the west and north increased to gale force locally towards the end of the month. An hourly mean wind speed of 63 knots and a gust of 82 knots were recorded at the high-level station at Great Dun Fell (Westmorland) on the 29th.

STATISTICS OF THE SERVICES DIRECTORATE

The quantitative analyses in this section are intended to provide an indication of the distribution of work within the Directorate of Services and of the extent of the services provided.

TABLE I—NUMBERS OF OFFICES OF VARIOUS TYPES STAFFED BY THE METEOROLOGICAL OFFICE AND OPERATING ON 31 DECEMBER 1973

	Within U.K.	Overseas
Principal Forecasting Offices associated with the RAF ...	1	—
Main Meteorological Offices associated with the RAF	7	5
Subsidiary offices associated with the RAF	35	7
Observing offices associated with the RAF	6	3
Principal Forecasting Offices associated with civil aviation ...	1	—
Main Meteorological Offices associated with civil aviation ...	3	—
Subsidiary offices associated with civil aviation	12	—
Observing offices associated with civil aviation	7	—
Upper-air observing offices	8	5
Public service offices	6	—
CRDF offices	5	3
Port Meteorological Offices	6	—
Offices associated with the Agricultural Development and Advisory Service (MAFF)	3	—
Other offices	26*	3

* Four of these stations are administered by DR Met O

Notes

A Principal Forecasting Office meets the needs of aircraft flying over long distances and operates throughout the 24 hours.

A Main Meteorological Office operates throughout the 24 hours for the benefit of aviation and normally supervises the work of subsidiary offices.

A subsidiary office is open for that part of the day necessary to meet aviation requirements.

At an observing office no forecaster is available.

An upper-air observing office may be located with an office of another type if this is convenient.

Public service offices are located in certain large cities.

CRDF offices form the network for thunderstorm location.

Port Meteorological Offices are maintained at the bigger ports.

TABLE II—OCEAN WEATHER SHIPS

To meet its obligation under the ICAO North Atlantic Ocean Station Agreement the United Kingdom operates four Ocean Weather Ships which work in rotation with two ships from France, one ship from the Netherlands and two ships jointly operated by Norway and Sweden The British ships serve at four of the five ocean weather stations in the eastern North Atlantic. each vessel makes, on average, eight voyages a year and spends an average of 24 days on station during each voyage. Some statistics for 1973 for the British Ocean Weather Ships are shown below.

Total number of days on station ... 716·3

Total number of days on passage ... 159·6

	Station A	Station I	Station J	Station K*
	average number per voyage			
Aircraft contacted	126	136	250	—
Number of aircraft given one or more radar fixes	78	88	180	—
Weather messages to aircraft	7	5	15	—

* During 1973 Station K was operated by France and for one voyage only, by the Netherlands.

TABLE III—MERCHANT NAVY SHIPS

A total of about 6900 ships of the merchant navies of the world make and transmit meteorological reports to the appropriate meteorological centres ashore under arrangements co-ordinated by the World Meteorological Organization. Most of them, including British ships, do this on a voluntary basis. Ships which report in full at four specified times daily are known as 'selected ships'; those which report at the same times daily, but in a less complete form, are known as 'supplementary ships'. A number of coasting vessels, lightships, distant-water trawlers and 'auxiliary ships' also make and transmit meteorological observations.

On 31 December 1973 the numbers of British ships reporting were:

Selected ships	531
Supplementary ships	49
	including 21 trawlers
Coasting vessels	49
Lightships	15
Trawlers	12
Auxiliary ships	17
Total	673

The British Voluntary Observing Fleet includes ships of many shipping companies, and the numbers on the various routes are as follows:

U.K. to Australasia	69
U.K. to Far East	84
U.K. to Persian Gulf	33
U.K. to South Africa	51
U.K. to West Indies	33
U.K. to Atlantic coast of North America	77
U.K. to Pacific coast of North America	11
U.K. to South America	23
U.K. to European ports	52
U.K. to Falkland Islands and Antarctica	3
U.K. to distant-water fishing grounds	21
World-wide tramping	123

During two typical days, one in June, the other in November, the number of reports from ships received in the Central Forecasting Office were as follows:

	Reports *June*	Reports *November*
Direct reception from:		
British ships in eastern North Atlantic	150	204
Foreign ships in eastern North Atlantic	55	9
British ships in North Sea	28	31
Foreign ships in North Sea	45	1
British ships in other waters	0	7
Total	278	252
Reception via other European countries:		
Ships in eastern North Atlantic	257	342
Ships in Mediterranean	77	24
Ships in North Sea	123	109
Ships off north Russia	23	6
Ships in other waters	29	6
Ships in Pacific	5	3
Total	514	490
Reception via U.S.A. and Canada:		
Ships in North Atlantic	582	649
Ships in North Pacific	733	831
Ships in other waters	52	75
Total	1367	1555

TABLE IV—CLASSIFICATION OF STATIONS RENDERING CLIMATOLOGICAL RETURNS

A large amount of meteorological data is obtained for climatological purposes from observing stations many of which are not part of the Meteorological Office organization. The following table shows how the sources of climatological information in the United Kingdom were distributed on 31 December 1973.

		Stations Supplying Returns					Stations Supplying Autographic Records		
	Observatories	*Synoptic*	*Agrometeorological*	*Climatological*	*Rainfall**	*Sunshine*	*Rainfall*	*Wind*
Scotland, north	1	9	0	32	309	25	8	16
Scotland, east	0	10	9	64	560	55	22	11
Scotland, west	1	14	1	54	531	29	26	17
England, north-east	0	10	5	23	529	27	15	11
England, east	0	11	13	21	563	31	12	12
England, Midlands	0	14	16	43	1424	59	17	17
England, south-east (including London)	1	19	21	48	867	63	27	23
England, south-west	0	15	7	30	576	35	7	8
England, north-west...	0	6	3	23	533	24	12	14
Wales, North...	0	2	3	15	300	11	2	3
Wales, South	0	7	9	17	420	22	3	4
Isle of Man	0	2	0	1	21	3	1	3
Isles of Scilly and Channel Isles ...	0	3	0	5	22	7	0	2
Northern Ireland	0	7	7	48	296	29	45	9
Total	3	129	94	424	6951	420	197	150

* Includes stations in earlier columns

TABLE V—HEIGHTS REACHED IN UPPER-AIR ASCENTS

The following table shows the number of upper-air ascents giving observations of (a) temperature, pressure and humidity and (b) wind, which have reached specified heights, and the height performance of the largest balloons.

(a) Observations of temperature, pressure and humidity

	Number of observations	Percentage of all balloons reaching				Percentage of largest balloons reaching
		100 mb 16 000 m (approx.)	*50 mb 20 000 m (approx.)*	*30 mb 24 000 m (approx.)*	*10 mb 30 000 m (approx.)*	*10 mb 30 000 m (approx.)*
Eight stations in the U.K. ...	5836	95·4	83·9	59·5	13·2	53·9
Five stations overseas	3284	96·9	82·7	56·8	4·0	56·3
Four Ocean Weather Ships ...	1482	95·2	82·8	52·6	1·0	—

(b) Observations of wind

	Number of observations	Percentage of all balloons reaching				Percentage of largest balloons reaching
		100 mb 16 000 m (approx.)	*50 mb 20 000 m (approx.)*	*30 mb 24 000 m (approx.)*	*10 mb 30 000 m (approx.)*	*10 mb 30 000 m (approx.)*
Eight stations in the U.K. ...	11 623	88·9	68·3	35·7	6·5	53·4
Five stations overseas	6 123	90·3	69·8	38·0	2·2	50·9
Four Ocean Weather Ships ...	2 900	85·9	62·1	29·7	0·5	—

TABLE VI—THUNDERSTORM LOCATION

Number of thunderstorm positions reported by CRDF network:

In 1973 ... ... 52 209

TABLE VII—METEOROLOGICAL COMMUNICATION TRAFFIC

Almost all the national and international exchanges of meteorological data which are used in the construction of synoptic charts and the production of forecasts are effected by coded messages. The coded messages are composed of groups of five figures and there may be from 5 to around 90 such groups in one message. The messages are exchanged by radio and land-line facilities. In addition there is an exchange, both nationally and internationally, of meteorological information in pictorial format. This information is largely analyses and forecasts derived from processing observational data. The transmission method is analogue facsimile by either radio or land-line.

The following figures give an analysis of the traffic (mainly coded messages and inforamtion in pictorial format) through the Meteorological Office Telecommunication Centre, Bracknell, for one typical day (24 hours) taken in November 1973 and, for comparison, some corresponding figures are given for one day near the end of 1972.*

	In	Out	Total	Total in 1972
Coded messages		*number of groups in one day*		
Land-line teleprinter and data transmission	1 003 327	1 255 771	2 259 098	911 178
Radio	202 489	240 360	442 849	447 565
Facsimile charts (pictorial format)		*number of charts in one day*		
Land-line	117	710	827	887
Radio	103	116	219	209

* The very large increase in coded messages compared with last year arises because some of the traffic now passing over the MTC must continue for the time being to pass over the old circuits as well.

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is a need for forecasts of a special type at certain seasons. These are described in Met O Leaflet No. 1 (1972). The numbers receiving such specialized services are as follows:

	Year	No. of customers	Year	No. of customers
Fine-spell notifications (a summer service primarily for farmers) ...	1972	223	1973	207
Week-end temperature forecasts (a winter service primarily for industrialists	1972–73	27	1973–74	27
Winter road danger warnings (primarily for local authorities)	1972–73	422	1973–74	427

TABLE IX—FORECASTS FOR AVIATION

Forecasting for aviation constitutes the primary function of many of the offices. The Central Forecasting Office acting as a Regional Meteorological Centre of the World Weather Watch is mainly concerned with the analysis of the weather situation and with the issue of forecast charts for the guidance of other offices. The Central Forecasting Office also has a commitment to aviation for the provision of forecast upper-wind and temperature charts for use with the significant weather charts produced by the Principal Forecasting Office at London/Heathrow and the transmission of grid-point forecast data direct to the BOADICEA and APOLLO computers at Heathrow and Prestwick respectively ann to the Belgian Meteorological Service in Brussels.

The following figures indicate the numbers of forecasts issued for aviation and the numbers of meteorological briefings that took place during 1972 and 1973. These do not include warnings and routine general forecasts.

	1972	1973
Number of meteorological briefings for		
aviation in the U.K.	414 748	327 334
aviation at overseas stations	36 868	42 284
Number of aviation forecasts issued for		
aviation in the U.K.	1 338 820	1 337 834
aviation at overseas stations	192 723	189 876

Note:

The fall in the number of meteorological briefings in the U.K. is largely associated with the introduction of a self-documentation service at Heathrow on 1 December 1972.

TABLE X—NON-AVIATION INQUIRIES

Non-aviation inquiries are handled by five Weather Centres, in London, Manchester, Glasgow, Southampton and Newcastle, and one other office in Nottingham (Watnall) whose function is to meet the needs of the general public for forecasts for special purposes. Many other forecast offices, established primarily to meet the needs of aviation, also answer requests for forecasts and other weather information, from the general public, Press, public corporations, commercial firms, etc. (The *Post Office Guide* lists 37 offices providing forecasts for the general public.) These inquiries, most of which refer to current or future weather, are listed below according to the purpose of the inquiry.

	1972	1973
Total number of non-aviation inquiries	1 582 129	1 745 888
Percentage relating to		
agriculture	9·6	10·5
building	5·0	5·3
commerce, industry	5·0	4·8
holidays	21·0	22·1
marine matters	16·2	14·7
Press	10·7	12·0
public utilities	9·1	9·2
road transport	9·3	9·2
other known purposes	6·7	5·5
unknown purposes	7·4	6·7

TABLE XI—FLASH WEATHER MESSAGES

FLASH weather messages are passed to the BBC for broadcast on radio, and to the BBC and most Independent Television Companies for inclusion in their programmes at a convenient break. They are, effectively, warnings of the actual occurrence of weather conditions which might cause considerable inconvenience to a large number of people. The following table shows the kind of weather and areas of the country for which FLASH messages are broadcast and the number issued in 1973.

Area	Dense fog	Moderate or heavy snow	Heavy rain	Severe inland gales
Edinburgh and south-east Scotland	—	1	1	—
Glasgow and south-west Scotland	1	1	1	2
Belfast and Northern Ireland	—	—	—	—
Industrial north-east England	1	1	1	—
Industrial Lancashire and Merseyside ...	2	1	2	—
Industrial Midlands	4	1	2	—
Bristol and Bath	1	—	2	2
South Wales	—	—	3	3
London and south-east England	—	—	2	—
Plymouth and south-west England	—	—	1	—
Yorkshire	1	—	2	1
Southampton and Portsmouth	—	—	—	—
Total	10	5	17	8

TABLE XII—AUTOMATIC TELEPHONE WEATHER SERVICE FORECASTS

The total number of calls made on the service during 1973 showed an increase of 20 per cent over the previous year.

Forecasts were available at 54 Post Office Information Centres for 25 forecast areas.

Information Service Centre	Forecast area	Number of calls 1972	1973
Bedford	40 miles radius of Bedford	161 342	197 426
Belfast	Belfast	180 158	228 800
Birmingham	Birmingham	598 141	755 126
Bishops Stortford	40 miles radius of Bedford	24 060	47 756
Blackburn	Central Lancashire	140 041	178 175
Blackburn	Lancashire coast	65 864	86 377
Blackpool	Lancashire coast	148 665	188 646
Bournemouth	South Hampshire	196 911	242 977
Bradford	Leeds, Bradford, Huddersfield	87 438	104 758
Brighton and Hove	Sussex coast	449 781	509 553
Bristol	Bristol	477 711	643 780
Cardiff	Cardiff	385 268	549 603
Canterbury	Kent coast	171 205	213 239
Chelmsford	Essex coast	85 578	106 139
Cheltenham	South-west Midlands	71 485	93 053
Chester	Chester and North Wales coast	116 056	143 571
Colchester	Essex coast	185 314	199 144
Colwyn Bay	Chester and North Wales coast	64 006	82 431
Coventry	Birmingham	99 934	149 972
Derby	Nottinghamshire, Derbyshire, Leicestershire	110 029	159 787
Doncaster	Sheffield, Chesterfield, Doncaster, Barnsley	29 501	39 358
Edinburgh	Edinburgh	279 071	340 328
Exeter	South Devon and east Cornwall	112 668	134 931
Glasgow	Glasgow	450 266	577 632
Gloucester	South-west Midlands	134 430	149 741
Grimsby	North Lincolnshire and Retford area	34 353	42 278
Guildford	London	81 773	98 051
Hereford	South-west Midlands	61 707	82 047
High Wycombe	Thames Valley	44 845	70 478
Huddersfield	Leeds, Bradford, Huddersfield	53 324	68 949
Ipswich	Norfolk and Suffolk	59 850	125 147
Leeds	Leeds, Bradford, Huddersfield	249 108	293 234
Leicester	Nottinghamshire, Derbyshire, Leicestershire	245 923	243 626
Lincoln	North Lincolnshire and Retford area	23 366	23 775
Liverpool	South Lancashire and north Cheshire	197 741	246 677
Liverpool	Lancashire coast	69 341	104 844
Liverpool	Chester and North Wales coast	56 172	72 947
London	London	2 663 985	2 897 866
London	Essex coast	142 762	144 162
London	Kent coast	162 925	162 145
London	Sussex coast	316 387	295 639
London	Thames Valley	139 995	147 832
London	40 miles radius of Bedford	74 860	82 726
Luton	40 miles radius of Bedford	95 924	120 139
Manchester	South Lancashire and north Cheshire	330 995	400 826
Manchester	Lancashire coast	84 984	101 556
Manchester	Chester and North Wales coast	68 529	74 046
Medway	Kent coast	103 213	129 945
Middlesbrough	Tyne, Tees	115 453	151 587
Newcastle	Tyne, Tees	261 647	324 176
Norwich	Norfolk and Suffolk	79 878	153 305
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	414 415	535 018
Oxford	Thames Valley	165 984	197 532

TABLE XII (*continued*)

Information Service Centre	Forecast area	Number of calls 1972	1973
Peterborough	40 miles radius of Bedford	48 177	62 205
Plymouth	South Devon and east Cornwall	186 555	202 847
Portsmouth	South Hampshire	286 447	357 234
Reading	Thames Valley	224 515	251 790
Sheffield	Sheffield, Chesterfield, Doncaster, Barnsley	218 644	285 482
Southampton	South Hampshire	328 244	392 740
Southend	Essex coast	141 195	148 646
Southport	Lancashire coast	50 024	61 530
Swindon	Bristol	32 235	37 962
Torquay	South Devon and east Cornwall	75 583	95 032
Tunbridge Wells	London	44 807	92 838
Total		12 860 788	15 501 162

TABLE XIII—CLIMATOLOGICAL INQUIRIES

Met O 3, Met O 8, Edinburgh and Belfast receive a number of inquiries relating to past weather, to climatology and to the application of meteorological data to agriculture. The following figures give the total number of inquiries and the percentages of this number in various categories.

	1972	1973
Total number of climatological inquiries	15 269	17 046
Percentage relating to		
agriculture (farming, forestry, market gardening)		11·8
building and design (including siting)		16·8
commerce (sales, marketing, advertising)		5·1
drainage		1·9
education and literature		6·2
flooding		0·4
heating and ventilation		2·1
industrial and manufacturing activities		4·3
law (damage, accident, insurance)		15·2
medical and health		1·1
Press and information centres		3·3
research		8·4
sport, hobbies, holidays		1·5
transport and communications		1·9
water supplies		7·2
miscellaneous (purpose known)		4·8
miscellaneous (purpose unknown)		8·0

TABLE XIV—DATA PROCESSING

(a) Punched-card installation

Number of cards punched by the Meteorological Office installation	989 511
Number of cards punched elsewhere on behalf of the Meteorological Office ...	52 956
Number of cards converted from paper tape	60 500
Number of non-routine investigations completed	98

(b) Processer-controlled keying system

The processer-controlled keying (PCK) system was used for data preparation during 1374 hours.

(c) Computer installations

(1) The KDF9 computer (COMET) was used for computing during 609 hours.

(2) The 360/195 computer was used for computing during 8490 hours.

TABLE XV—INSTRUMENT TESTING AND CALIBRATION

The numbers include those of instruments tested or calibrated for outside authorities on repayment.

	Number of tests or calibrations
General meteorological instruments*	42 632
Balloons	70 910
Radiosonde batteries	25 997
Radar reflectors	28 960
Electrical/electronic instruments and systems	780
Electrical/electronic components	67 290
Radiosondes, calibrated†...	16 321
Total	252 890

* The total for general meteorological instruments includes calibration of 667 Precision Aneroid Barometers and certification of 1272 Mercury-in-Glass Thermometers.

† In addition, 2335 radiosondes were recovered after flight: 754 of these were repaired and recalibrated for further use, the remainder being stripped of re-usable components.

THE DIRECTORATE OF RESEARCH

Special Topic—Research on the Structure of the Lowest Kilometre of the Atmosphere

The detailed structure of the atmosphere near the ground is of special interest in several respects. In addition to the direct climatological significance to human, animal and plant life, it is through the lowest layers of the atmosphere that the energy input to weather systems largely occurs, and it is into these layers that the gaseous products of heating and industrial processes are injected. In all these respects a common point of interest is the diffusive character of the air as regards its content of momentum, heat, water vapour and particulate matter.

Except in special circumstances this diffusive quality is very much more effective than that which arises from the random motion of molecules. It is a consequence of the larger-scale mixing actions of turbulence, which is generated partly mechanically, as a result of the aerodynamic friction of the earth's surface, and partly as a result of buoyancy forces arising from heating of the surface.

One of the exceptions to effective mixing arises when the surface is substantially colder than the air above it, a circumstance which is familiar on clear nights with a light wind, and which is associated with the incidence of dew, ground frost, mist and fog. A common feature of all these phenomena is that the diffusive action of the air especially in the vertical has been reduced or even completely suppressed by stabilizing buoyancy forces. These latter forces are brought into action when the density of the lower layers is increased relative to those above, as occurs when the lower layers are cooled by contact with ground which has been cooled by radiation, so producing an *inversion* of temperature, which is in contrast to the otherwise normal decrease or *lapse* of temperature with height. The mixing of pollution in these conditions will be less effective and so, if the release of the pollutant is near the ground, dilution will proceed only slowly and high concentrations will tend to occur.

Even when the conditions are conducive to effective mixing near the ground the action is usually confined to a layer of limited depth—one kilometre is a typical midday magnitude but it varies considerably. This limitation in depth is often sharply defined by an overhead stable layer, in which a temperature inversion occurs, but such elevated stable layers are a consequence of atmospheric processes on a larger scale and without restriction to night-time. The existence in this way of a definite top to the *boundary layer* or *mixing layer*, as it is variously termed, is a characteristic feature of settled weather, and in these circumstances it is only when the stable layer is penetrated by warm air from below that the airstream begins to develop large cumulus clouds, showers and ultimately thunderstorms.

At other times there may not be a sharply defined top to the mixing layer, but merely a gradual merging into the free atmosphere above. The effects of the boundary layer are then transmitted to the atmosphere at large in a more gradual way, by the slow ascent of air as a result of converging winds, or by the upward penetration of convective columns of buoyant air in clouds and elsewhere.

These references to the interaction between the boundary layer and the free atmosphere have been made because they involve the evolutionary character of the layer and its role as a temporary store for important properties such as heat, moisture and pollution. The studies of atmospheric boundary-layer phenomena were for a long time conducted without particular recognition of these aspects. Moreover because of practical limitations in the past special observations were often limited to a few tens of metres above ground. Accordingly we now have a fairly advanced knowledge of the vertical transfers of atmospheric properties in the lowest part of the layer. However, the last decade has seen the development of interest in the wider implications of boundary-layer action, and the growth of demands for 'models' of the layer which can be incorporated in theoretical studies of local weather phenomena, and in the numerical methods applied in weather forecasting and studies of the general circulation of the atmosphere.

These interests and requirements have stimulated boundary-layer research in two main directions: first in the extension of the specialized observations of atmospheric turbulence (and its effects on diffusion) to the upper parts of the layer; secondly in the development of more complex mathematical representations of these properties. In the Meteorological Office programme of physical research these requirements have been recognized by a closer co-ordination and redevelopment of the work on turbulence and diffusion, in which effort has been concentrated on the building up of facilities for the special measurements and on those theoretical aspects which have an important bearing on practical aspects of meteorology in general, as well as on the long-standing problem of dispersion of pollution.

Instruments

For the basic measurements of the turbulent fluctuations of the wind and other atmospheric properties it has usually been necessary to develop instruments and recording systems of a special nature differing from those used in routine meteorological observations. In the Meteorological Office's programmes these have had to be designed not only with adequate response to the rapid variations which have to be followed, but also in a form suitable for exposure on the swaying cable of large tethered balloons, so as to make the measurements at heights well beyond the reach of normal towers and masts. Responsive vanes for recording the vertical inclination of the airflow were used at an early stage but it has been necessary to refine and extend the equipment in many ways.

In its latest form, as developed over the last five years, the instrument package consists of a responsive cup-rotor for measuring wind speed, two hot-wire 'yawmeters' for the horizontal direction and vertical inclination of the wind and fine-wire resistance thermometers for air temperature. A version is also available for use at sea in which a temperature element is used in wet-bulb form for measuring humidity, but at present without the wind-direction yawmeter.

For mounting on the balloon cable the instruments are assembled on a large vane which directs them into the general wind direction irrespective of twisting of the cable. One of the more difficult problems to be overcome was the provision of a reference direction and after investigating various alternatives a magnetic system giving reference to the earth's magnetic field was adopted and successfully incorporated in the equipment. Initially the signals from such

a package of instruments had to be transmitted to the ground by cables, but it has always been clear that multi-level measurements would be feasible only if the complication of many conducting cables was avoided. Another important stage has accordingly been the development and incorporation of a radio-telemetry system and this has now been completed.

The instrument package and its supporting vane are designed to maintain the sensors in a reference frame of known orientation, despite the swaying and twisting of the balloon cables. However, there is also an unavoidable bodily motion of the sensors and it has been necessary to conduct tests both in the laboratory and the field on the spurious indications so produced. It has finally been confirmed, by direct comparisons with measurements made simultaneously on a high tower, that the properties of turbulence may be recorded with negligible error for present purposes as long as the instrument package is mounted a sufficient distance (say 200 m) below the balloon itself. In operations at sea there is yet another complication from the tightening and slackening of the cable caused by the heaving of the ship, so leading to troublesome oscillations of the instruments. To overcome this difficulty a servo-system has been incorporated in the winch control to provide continuous correction to the payout of the cable.

Field studies

With the instrument development at such an advanced stage, it has been possible to make a start on comprehensive multi-level studies of turbulence fluctuations throughout the whole depth of the boundary layer. In the interim period these studies were somewhat restricted in scope. Nevertheless certain special features of boundary-layer description and action have already been brought out as a result of the preliminary measurements.

One of the first useful steps, provided by ascents with a single instrument package, was a demonstration of how the vertical distribution of the small-scale turbulence in the first kilometre is related to the heating of the ground. Important deductions may be made from such measurements, in particular the confirmation that with little or no surface heating the rate of generation of turbulent energy falls off markedly from the surface. On the other hand with substantial heating of the surface the rate of generation is maintained (by convective motions often manifest as the thermals well known to glider pilots) with little reduction throughout the whole mixing layer.

The vertical profiles of the levels of turbulent energy actually attained depend on a complex balance between the generative, diffusive and dissipative actions and this is one of the many features which will be fully understood only when the much more comprehensive observations have been obtained. However, the early observations have already led to a useful generalization for convective conditions, in which the standard deviation of the vertical component of air motion is approximately proportional to the cube root of the product of height and heat flux.

Considerable effort has been put into a unique study of the detailed structure of the interface at the top of the fine weather mixing layer, using the captive balloon system in conjunction with remote scanning of the same region of air by means of a high-powered radar. These observations have already provided an improved understanding of the important actions at such an interface, through which air from the warm stable layer above is intermittently entrained into the

mixing layer below, carrying with it a significant contribution to the heating of that layer.

In a contrasting context, measurements have also been contributed to the Office's programme of study of the physical processes controlling the formation and dissipation of fog. Observations of turbulence in the stabilized surface flow produced by radiative cooling are an essential component in the study of conditions preceding fog, as well as providing basic information on the mechanics of the flow.

Effective use of the captive-balloon system has been included in the growing multi-disciplinary study of air–sea interaction. So far there have been two co-operative projects—the North Atlantic Trade Wind Expedition in 1967, and the Joint Air Sea Interaction (JASIN) experiment organized by the Royal Society in 1970. Although the instrumental development was still incomplete by the latter date, some 30 hours of turbulence records were obtained at two or three heights simultaneously up to about 200 m over the North Atlantic. The results are a useful contribution to the knowledge of vertical transfer of heat and water vapour over the sea, and have underlined the importance of the moisture content of the air in the buoyancy forces controlling the turbulence. The experience has also been invaluable as practice for participation in more elaborate experiments planned as part of the Global Atmospheric Research Programme (the GARP Atlantic Tropical Experiment, GATE, in 1974) and the continuation of the Royal Society JASIN experiment in 1976.

At the time of writing the first full results of multi-level observations over land are in process of analysis. In particular a major co-operative study of the boundary layer over flat and relatively uniform terrain, planned some years ago with the U.S. Air Force Cambridge Research Laboratories (AFCRL) has just been completed. After a period of testing and comparison of the respective instrumental systems the joint observational programme was mounted in Minnesota in September 1973. Here the Cardington system was flown to give complete turbulence observations at five levels (from 200 ft up to 2000 or 4000 ft) in conjunction with the AFCRL tower installation of sonic anemometers at two lower levels (see Plates IV and V). The 70 hours of observation at seven levels, obtained in seven main periods with various supporting observations of the meteorological conditions, are expected to provide a major step in boundary-layer climatology.

Theoretical and analytical studies

Although some part of the theoretical effort is still demanded by air-pollution problems there has been a substantial swing of interest to features which are of importance in the development of the other aspects of meteorology.

In earlier considerations of the boundary layer as a whole the system was treated as if in a simple steady state, with the transfer properties envisaged as constant in space and time. More recently there has been increasing engagement with the evolution of the layer in response to important changes in surface roughness or to the 24-hour cycle in the heating and cooling of the surface.

Starting with a simple heat budget approach an analytical model has been developed to represent the day-time evolution of a dry, convectively unstable layer capped by a deep stable layer. Outstanding features are the recognition of the cumulative effects of the input of sensible heat and of the addition made

to this by the transfer downward through the capping interface, as referred to in the previous section. This simple model immediately provides reasonable agreement with existing data on diurnal development of the depth of mixing. Improvements under consideration include the effect of wind shear at the top of the layer, though in this more elaborate model further progress has required numerical (rather than analytical) integrations. Parallel analyses of the data from special radiosonde ascents have led to an estimate of about $\frac{1}{4}$ for the average ratio of the downward rate of heat transfer through the cap to the upward transfer from the heated ground. This result refers to a day-time mixing layer typical of anticyclonic conditions in an English summer. The data have also been used as a check in the early development of a model representing the entrainment action of Kelvin–Helmholtz waves on the interface.

The theoretical examinations may now be pressed forward in closer co-ordination with the mounting observational studies provided by the captive-balloon facility. One of the issues requiring much further clarification is the detail of the vertical-transfer relationship through the whole depth of the mixing layer. Much of the work so far has been based on representations analogous to molecular action, with a large-scale 'mixing length' replacing the molecular 'mean free path'. This length is not measurable in any normal sense and serves its purpose mainly in a mathematical sense, by providing convenient 'closure' of the complex sets of equations which would otherwise have too many unknowns for solution. An alternative formulation of the transfer uses information on the directly relevant properties of the vertical component of turbulence, which are now observable throughout the boundary layer. This approach has been developed for the treatment of the vertical dispersion of pollution but the same formulation may be a preferable alternative in certain meteorological problems.

Real progress in the fundamental understanding of turbulent action in the boundary layer is believed by many to require ultimately something beyond the relatively simple 'diffusivity' approach referred to in the preceding paragraph. There are now in vogue various attempts to improve the 'closure' techniques for the basic equations in a more rational way; especially now that numerical solutions may be contemplated on a scale unthinkable even a decade ago. The economic justification for and practical advantages of very elaborate mathematical modelling of the boundary layer obviously needs very careful consideration. Certainly one of the essential prerequisites in such considerations is the provision of a sound quantitative basis for the relations which still need to be postulated between the variances, covariances and even more complex statistical properties of the turbulent fluctuations. This is another aspect for which the Office's long-term programme of special observations is of particular importance.

In parallel with the more basic examination of boundary-layer behaviour various *ad hoc* analyses are also undertaken to provide advice on practical and operational problems arising in other aspects of the Office's work. Examples are the morning breakdown of nocturnal inversions, the warming of air flowing over relatively warm sea, the development of country-wide maps of effective surface roughness, the specification of the intensity of vertical transfer in terms of 'stability categories' defined in terms of routine meteorological data, formulation of broad rules for specifying the vertical profile of wind speed, and the

problems arising in specifying boundary-layer transfers of momentum and energy in numerical forecasting procedures.

Applications in problems of air pollution

The now traditional meteorological problem of the local air pollution arising from domestic heating, power stations and industrial plant continues to be of practical interest and to pose demands for up-dating and extension of working methods formulated more than 10 years ago. That system has been used widely with minor modifications here and there. Some of the more speculative features of the prediction of vertical dispersion from a ground-level source have recently been eliminated, and improvements in the prediction of cross-wind dispersion are currently under consideration. Attention has also been given to the accuracies which may be expected in the prediction of air pollution from meteorological data and to preliminary theoretical considerations of the effect of the inflow of wind which tends to be generated over large urban areas.

The foregoing methods of calculation of air pollution require specification of the rate of emission of the pollutant, and for the important case of the complex array of sources in a typical urban–industrial area the requirement for an 'emission inventory' is a major problem. A practical alternative, which is virtually essential for day-to-day operational estimates or forecasts of urban levels of pollution, is to make use of the past experience of the levels of air pollution. Such data take into account general magnitude and disposition of the sources; and the departures of the air-pollution concentration from immediately preceding levels or from long-term average levels may be expected to be closely correlated with the meteorological variables, notably those of wind speed (as essentially representing the dilution) and air temperatures (partly representing variations of fuel consumption for heating purposes). A promising system developed along these lines is now under test in London.

Recently the much longer-range transport of industrial air pollution has attracted special interest as a result of the Swedish consideration of the acidity of rain and its possible ecological effects. As part of a national programme co-ordinated by the Department of the Environment, and carried out in conjunction with the Atomic Energy Research Establishment (AERE) Harwell, the feasibility has been demonstrated of measuring sulphur pollution from a Meteorological Research Flight aircraft flying at various levels in the mixing layer. These measurements may be used to make an estimate of the total quantity of pollution remaining airborne downwind of major sources of pollution. Early flights in this programme have indicated that in dry westerly airflow over England roughly half the pollution injected *en route* is carried across the east coast. Additional flights are being carried out to provide a better statistical estimate of this fraction, and also possibly to obtain an estimate of the further reduction of the pollution content during the travel over the North Sea.

The loss of sulphur pollution in dry conditions is believed to be mainly a consequence of absorption of sulphur dioxide at the earth's surface, and an additional check on the magnitude of this deposition has been obtained from measurements (on a mast) of the low-level vertical profiles of sulphur dioxide, wind and temperature, in conjunction with AERE Harwell. The latter type of data may be used to estimate the downward transport of sulphur dioxide to the surface by the technique familiar in estimating evaporation from a natural surface.

The European interest in the long-range transport of industrial air pollution has led to the setting up of a co-operative sampling experiment by the Organization for Economic Co-operation and Development (OECD). In addition to the provision of sites for five sampling stations in the U.K., there has been a growing need for air-trajectory analyses in which the tracks of air starting from designated positions are worked out step by step from the wind fields of weather charts. These analyses are required partly to understand specific pollution 'incidents' as observed in the OECD sampling network, and partly in the more general consideration which is being given to the basis for modelling long-range diffusion. The recent progress in the OECD study is now being appraised, in both national and international meetings, so as to decide on the initial implications and future course of the co-operative experiment.

Physical Research

Cloud microphysics

Experimental and theoretical investigations have been carried out into the growth of water droplets and ice crystals in clouds with the objective of understanding more fully the mechanisms of rain formation. Without this knowledge there can be no prospect of understanding thoroughly the ways in which clouds and rainfall may be modified by man's activities—intentional or inadvertent. Instrumentation is being developed for use on the new C-130 Hercules aircraft of the Meteorological Research Flight so that observations can be obtained with which the results of theoretical and laboratory studies can be compared.

Calculations of the development of the drop-size spectrum by condensation in small cumulus clouds, using a simple one-dimensional model of the dynamics of the cloud, have shown that the observed bimodal form of the spectrum can only be reproduced if entrainment of drops from earlier decaying up-currents is included. Such a model of the growth of cumulus by the ascent and decay of successive rising thermals also predicts values of the updraught and liquid water content in these clouds which are more realistic than those predicted by previous one-dimensional models. An extension of the calculations to include the effects of coalescence has demonstrated that condensation and coalescence should not be treated as separate processes but rather that condensation, in acting simultaneously with coalescence, reinforces it. It has been demonstrated that drops of raindrop size may be grown by coalescence in maritime cumulus clouds only 2 km deep but that the growth of such drops in clouds containing a higher concentration of condensation nuclei will be much slower. In these clouds the growth is very sensitive to the values assumed for the efficiency with which drops of radius less than about 20 μm collect smaller droplets. Experiments in which small-scale atmospheric turbulence has been simulated in a small wind-tunnel have shown that in turbulent conditions the collection efficiencies of these droplets may be considerably increased over the values in still air and would, if applicable to small cumulus, increase the rate of production of raindrops in these clouds.

Laboratory studies of the growth of rimed ice pellets have shown that only small numbers of sub-micron ice splinters are produced during the riming

process. Although some extrapolation of these results is necessary before they can be applied to realistic cloud conditions it has been calculated that they fail to explain the difference of about a factor of 10 thousand between the observed ice-crystal concentrations in clouds and the observed ice-nucleus concentrations at the same level unless either the cloud summits had at some time been much colder than they were at the time of observation or that some recycling of the ice crystals through the cloud had occurred. In order to promote rapid glaciation of clouds at temperatures higher than those at which they would naturally glaciate, silver iodide has frequently been used as a seeding agent, but the way in which it acts as an ice nucleus, that is whether it nucleates drops by contact or whether it acts as a nucleus for the growth of ice crystals by sublimation, is not understood. Experiments are being carried out to determine the nucleating properties of silver iodide and similar materials in a diffusion chamber in which conditions simulate those in cumulus clouds.

Instruments are being developed to study the drop-size spectra and ice-crystal concentrations in clouds. A holographic system has been devised to measure low concentrations of large drops and ice crystals and has an advantage that the volume sampled in a very short period of time is much greater than that of other instruments and so does not smooth out variations between different regions in a cloud. The serious problem of the analysis of the holograms to obtain the size and positions of the drops and crystals is being investigated. For sampling smaller drops studies are being carried out of a light-scattering instrument and of an instrument which measures the shadows of drops cast over an array of fibre optics. Instruments to measure the electric field, conductivity and droplet charge in clouds, developed jointly with the University of Manchester Institute of Science and Technology, have been tested and the necessary interfaces and computer software have been produced to enable data to be obtained in a form compatible with analysis on the IBM 360/195 computer. Data received from a test flight enabled the electrical properties of an inversion to be explored and a simple mathematical treatment of the electrical and turbulent diffusion processes predicts many of the observed features.

Dynamics of precipitation systems

Analysis of the data obtained in Project Scillonia, the project designed to study the dynamical structure of warm fronts, has continued. The detailed studies of the wind fields have been associated with a climatological study of the occurrence of low-level wind maxima in frontal systems. The data have yielded fields of motion and fluxes of energy and momentum which are being compared with theoretical predictions. In an attempt to explain the rain-band structure associated with warm-frontal precipitation a theoretical study of instability in a stratified Ekman layer has been initiated in order to establish whether the structure is due to instability in the frontal shear zone.

Future studies of frontal systems will require data over a much larger area and from a greater height which will necessitate improved observational techniques as well as automated methods of data handling. Work is in progress on the design of a dropsonde which uses radio navigational aids to telemeter its position in order to measure its movements and hence the wind field. An objective analysis technique is also being developed to analyse the data. Earlier difficulties with the objective analysis technique were due to a lack of data in a

horizontal plane and these should be removed in future projects. Development of a special parachute for the dropsonde intended to eliminate any tendency to move horizontally relative to the air has shown that such a system has similar wind-following characteristics to the radar targets used in Project Scillonia. The use of either a radio altimeter or pressure transducers to measure the height of the sonde is being investigated and the performances of various types of humidity sensor are being evaluated. Tests of the system for ejecting the dropsondes in a capsule from the C-130 aircraft demonstrated that some of the capsules collided with the tail of the aircraft but calculations, later verified by tests, showed that the problem could be solved by altering the position of a raised seam on the capsule which had the effect of altering the drag of the air so that the capsules moved away from the aircraft rather than towards it.

Fog studies

Data obtained in a series of field experiments at Cardington on the formation, dissipation and properties of radiation fog have been analysed. While the major factors which determine the onset of radiation fog are reasonably understood, the role of microphysical processes is still not clear. A numerical model of radiation fog has been developed and includes the effects of radiation from the water vapour, carbon dioxide and fog droplets as well as the turbulent diffusion of heat, water vapour and droplets. The model predicts some of the observations quite well and has shown that gravitational settling of the fog drops plays a major part in decreasing the liquid water content in the fog. The treatment of the heat flux from the soil which is used in the model and of the turbulent-diffusion processes are being improved as the model is developed. The model is also being used to determine critical parameters to be measured in future field investigations.

Radar meteorology

The high-power radar at Defford has been used in several studies of clear-air turbulence and of low-level convection. Analysis of the data from the project in which the Canberra aircraft of the Meteorological Research Flight (MRF) flew through a train of large-amplitude billows in clear air at a height of 7 km, which were detected by the radar, has shown that moderate turbulence may be associated with the crests of such billows. At a lower level the radar has been used to measure the fine-scale structure of individual convective elements. These measurements are being compared with observations of vertical velocity and temperature structure obtained by the Reading University powered glider and with observations of the electrical properties of the air obtained using instruments on the Varsity aircraft of the MRF.

The mobile type 43S radar (10-cm wavelength) has been used in an extensive study of the effects of orography on precipitation. In particular, analysis of extensive data from a two-day period of heavy warm-sector rainfall has shown that potential instability may be released by orographic lifting of the air and that this may result in increased precipitation. Theoretical studies of this process and of the enhancement of frontal precipitation falling through lower-level cloud produced by ascent over mountains are also being carried out.

Radar can be used to obtain quantitative estimates of rainfall intensity from the intensity of the returned echo and a project is being undertaken to use a network of interlinked radars covering a wider area than is possible with

a single radar and to transmit digitized echo-intensity data along Post Office lines to a central processing point. The data will be used to study the mesoscale structure of precipitation systems and the rainfall information will be presented in an easily assimilated form on a television tube. As well as its value in research such a system of interlinked radars may be of considerable benefit to those concerned with the management of water resources and could also provide a means whereby short-period rainfall forecasts of high accuracy could be made.

Air pollution studies

As part of the WMO network a background pollution monitoring station is being established at Lerwick to measure contamination both in the air and in rain-water and the necessary instrumentation is being developed. A prototype automatically opening rain collector, which collects only water deposited as rain, and not fog or dew, has been working satisfactorily for 7 months. A comparison of the pollutant concentrations obtained with this instrument and those obtained using a permanently open collector suggests that the latter may be contaminated by sea spray especially during the winter months. Serious errors have been detected in the data obtained by using standard bubblers to collect air pollutants and a modified system, designed to remove the sources of error, is being tested. An instrument to monitor continuously the mass of particulates in the air is also under investigation.

Studies of the aerosol concentrations in the stratosphere which affect the heat budget of these air layers are being made. A balloon-borne instrument is being developed to measure the absorption of solar radiation by the aerosol by detecting pressure pulses produced by the intermittent conversion of energy into heat from a solar beam chopped at an audio frequency. A system of detecting the orientation of the instrument relative to the sun as it swings on the balloon cable is under construction and the complete instrument should soon be ready for testing.

The production of oxides of nitrogen in the stratosphere by supersonic transports and the effects on the ozone budget of the atmosphere have aroused considerable controversy. Calculations have shown that equivalent amounts of nitrogen oxides to those produced by large fleets of aircraft have already been injected into the stratosphere by nuclear test explosions. Analysis of the world-wide ozone records before and after the period of nuclear explosions shows that the massive amounts of nitrogen oxides produced in the nuclear tests have produced no detectable changes in the total ozone.

The atmospheric boundary layer

Observational and theoretical researches on the turbulent transport of heat, moisture, momentum and pollution in the lower layers of the atmosphere have continued.

The design and testing of the special instrumental systems for use with captive balloons have been in progress for several years and have now finally reached a stage adequate for multi-level observations of turbulence over both land and sea. More rapid progress in the basic understanding and practical representation of the action of the boundary layer may now be expected. A review of the background to these studies and of the latest progress is contained in the special topic of this report.

The scientific team at Cardington have now completed the field tasks in the joint boundary-layer study with the U.S. Air Force Cambridge Research Laboratories and a period of analysis and interpretation lies ahead. Preparations are well in hand for the participation in the boundary-layer sub-programme of GATE by the scientific staff at Porton, who also provide the meteorological assistance required by the Chemical Defence Establishment and the Microbiological Research Establishment.

Studies related to air pollution

The studies of atmospheric diffusion continue to be applied to problems of air pollution from fuel combustion and industrial processes, on both local and continental scales. Recent developments, notably in regard to forecasting sulphur-dioxide levels in London and to the OECD co-operative study of European sulphur pollution, are summarized in the special topic.

High atmosphere

Two firing campaigns with SKUA rockets were undertaken at the West Geirinish range to test the feasibility of a double pay load, a temperature-measuring sonde and a chaff charge, which together are intended to measure temperatures from about 65 km downwards and wind speed and direction from about 80 km downwards. Two ground-based radars are necessary to complete the system, one being used to track the chaff and the other the parachute from which the temperature sonde is suspended. During the first campaign in February the performance of a newly installed X-band radar was tested in the parachute tracking role and found to be inadequate. The original S-band radar, which has been available at the range for many years, was easily able to track both the chaff and the parachute but, of course, not at the same time. A new light-weight version of the parachute was tested; it deployed and functioned well. The X-band radar was used in a chaff-tracking role during the second campaign in May but again its performance was quite inadequate, so recourse had to be made to the use of a second S-band radar installed some 75 miles distant at the upper-air station at Stornoway. Although the use of two radars at two separate sites presented some operational problems, their combined use proved to be quite feasible and gave good results. During this second campaign a newly fitted fast print-out system was used on the West Geirinish radar to provide detailed sonde-fall data for the first time. The X-band radar was used in the determination of ballistic winds which are required for the safe firing of rockets.

A low-dispersion version of the normal rocket, SKUA 4, was fired at Aberporth in August. It achieved an apogee of 115 km and pay load deployment was normal.

A compact portable ground station for the standard SKUA system was built for use in international rocket sensor comparison trials which were organized by the WMO Commission for Instruments and Methods of Observation (CIMO) and held at Kourou in French Guiana in September/October. The U.K. participated in these trials together with the U.S.A., the U.S.S.R. and France. In all the U.K. launched 12 rockets, the first of which was a system-trial round. Of the 11 others, 9 were completely successful in that full data were recovered and the remaining 2 were partially so. Final processing of the data so acquired has been completed and forwarded to the CIMO Rapporteur.

The U.K. data are in good agreement with those of France and the U.S.A., but temperatures measured by the U.S.S.R. above 40 km progressively diverge from the former group to reach a mean value of about 20 degC colder at 65 km.

Observations of winds and temperatures obtained from 24 rocket soundings at Gan (0°43′S, 73°09′E) on three separate nights in September and October 1972 have been analysed. Large-amplitude oscillations of the meridional wind can be identified and are probably associated with the diurnal and/or semi-diurna latmospheric tides whose phase changes with height. Large-scale patterns of changes in the zonal winds and in temperatures over the 10-hour observation periods have also been observed. In the middle and upper stratosphere large temperature deviations from a smooth profile showed little vertical movement but at certain levels considerable temperature changes occurred during the course of a night. The data obtained from the intercomparison trials at Kourou (5°12′N, 52°44′W), referred to above, show similar features.

No experiments were flown on large rockets in 1973 but analysis of past data so acquired has continued. The computation of measurements of ultra-violet albedo and night-time ozone concentration made by a photometer on the moon-pointing SKYLARK round in October 1972 have been completed and a paper on each topic has been submitted for publication. The values obtained for lunar albedo were significantly higher than those published previously but were still consistent with the notion of a gradually decreasing albedo with decreasing wavelength as indicated by ground-based measurements in the visible spectrum. The ozone-content measurements made between heights of 65 and 75 km were in agreement with previous measurements using rocket-borne sensors but were markedly higher than results recently obtained by satellite-borne instruments using a stellar occultation technique.

The analysis of water-vapour, ozone and molecular-oxygen measurements made on earlier SKYLARK flights is continuing. In particular, computations of water-vapour content show that the stratosphere is essentially dry with concentrations decreasing from a value of 1·5 micrograms per gram of air at 20 km to about half this value at 35 km.

Preliminary work on the design of experiments to determine the diurnal variation of ozone in the mesosphere using the smaller PETREL rocket has commenced. The problem of the measurement of rocket attitude during night-time flight using the moon as a reference has been the main concern to date.

Work has continued in co-operation with the National Physical Laboratory on the development and testing of a broad-band balloon-supported radiometer which is eventually intended to measure ozone, water-vapour, and carbon-dioxide content in the atmosphere from various heights to the top of the atmosphere. The first flight of a prototype instrument took place in November and results are being analysed.

The meteor trail Doppler radar, an equipment designed to measure wind in the 80–100-km height interval by observation of the movement of ionization produced by meteors, has been progressively modified to enable a location of the reflecting ionization to be made. At the end of the period under review a system of phase comparisons between the reflected signals received at three separate aerials appeared to be giving good results. Trials will continue to determine the best spacing between the aerials to avoid ambiguity in the measured angles of arrival of the signals and to assess the suitability of the

present site on which the equipment is located for this work. If present trends continue, routine operation should be possible within a few months.

The high-power laser for the investigation of atmospheric density and aerosol distribution has been operated under trial conditions and has given encouraging results. Some operational problems have arisen but the difficulties have been overcome as they developed. Trials are continuing. An investigation into the behaviour of photomultipliers, an essential part of equipment of this type, has shown that some previously published laser radar results by others may need reassessment.

The measurement of total atmospheric ozone amounts by ground-based observations using Dobson instruments at Bracknell, Lerwick and Gan has continued on a routine basis as a contribution to the world-wide monitoring network. The instruments in use have been compared with those at Arosa, Switzerland.

International co-operative satellite projects

Two such projects have been supported during the year. METEOSAT, one of the European Space Research Organization (ESRO) 'application' satellites, has demanded some 'in house' studies and attendance at a considerable number of European working-group and committee meetings. In particular the Office has provided the Chairman of the meteorological software definition group and that of the scientific and technical group, the latter reporting to the Programme Board on which the Director-General is one of the two U.K. members. The work of the first of these groups will be taken over by ESRO staff in 1974.

Steps towards the provision of stratospheric sounding units to the National Oceanographic and Atmospheric Administration (NOAA) of the U.S.A. for inclusion in the next generation of operational meteorological satellites under a co-operative agreement have been actively pursued. The preliminary design work commenced last year was successfully concluded and resulted in the selection of a specific type of instrument and a decision to go ahead with the programme. A contract has now been placed with Marconi S.D.S. Ltd for further engineering development which will lead to the construction of flight models of the stratospheric sounding units to be supplied to NOAA from 1976/77 onwards. In exchange we will receive the data gathered by the full range of instruments to be carried in the satellite.

Interpretation of satellite-borne radiometer measurements

Research has continued into the methods of deduction of horizontal and vertical temperature structure of the atmosphere from the measurement from satellites of the radiant energy leaving the top of the atmosphere. A knowledge of temperature structure at least on a semi-global basis is one of the main requirements for the application of forecasting methods, especially those which depend on numerical models of the atmosphere. Radiances measured by the Oxford–Heriot-Watt University Selective Chopper Radiometer flown on NIMBUS 5 have been used to construct charts of the mean daily 100–3-mb and 3–1-mb thickness patterns for a four-day sample period and some comparisons have been made with rocketsonde observations. 'Window' channel radiances measured by the same instrument and by the American vertical temperature profile radiometer (VTPR) on the NOAA 2 spacecraft are being studied to see

whether they can be used to construct charts of sea surface temperature. These temperatures are required for the deduction of vertical temperature profiles down to the earth's surface and for the avoidance of wrong deductions from radiance measurements made under cloudy conditions. Radiance measurements made by the VTPR are also in use to construct charts of temperature and thickness in the range 10–300 mb over Europe for sample periods for comparison with radiosonde observations.

As a supporting investigation, and for the development of the stratospheric-sounding unit referred to above, a computer program has been written to aid calculation of the transmissions of atmospheric gases and laboratory 'vacuums' from spectral data. Earlier work at Oxford University has been used as a basis.

Thickness values derived at Oxford University from NIMBUS 4 Selective Chopper Radiometer results have been used to construct contour charts of the 10-, 3- and 1-mb pressure surfaces during selected periods in the northern winter of 1971–72. For the 10-mb pressure surface the differences between charts based on the radiometer results and those based on radiosonde observations were generally small except during periods when the stratospheric winter warming phenomena occurred when large systematic differences were found. For January and February 1973 careful subjective analyses have been made of thickness and contour charts at levels between 100 and 10 mb in order to facilitate comparisons of data derived from NIMBUS 5 observations with those based on radiosonde and rocketsonde observations.

Work has continued on methods of calculating vertical motion in the stratosphere at levels up to 1 mb. Both radiosonde and satellite data have been used and some progress has been made towards obtaining comparable values based on the vorticity equation, integrated downwards through the atmosphere. Vertical motion has also been estimated from the more commonly used adiabatic equation which requires an accurate knowledge of the temperature and height fields.

Meteorological Research Flight

The Meteorological Research Flight (MRF) is based at the Royal Aircraft Establishment, Farnborough, Hampshire and is at present equipped with three aircraft, a Canberra, a Varsity and a C-130 (Hercules). The Hercules aircraft was delivered towards the end of the year after extensive modifications lasting 2½ years. When the Hercules has been thoroughly tested and calibrated the Varsity aircraft will be given up—probably in mid 1974.

During 1972 arrangements were made for the participation of the Canberra in a multi-aircraft project to measure wave momentum flux (code name WAMFLEX) over the Colorado mountains. Although the project was initiated by the U.S. National Center for Atmospheric Research, MRF scientists participated fully in the definition of the scientific objectives and in the determination of optimum flight plans for their fulfilment. The project took place during January to March of 1973, statistically the most favourable time of the year for formation of well-defined and extensive mountain waves. During the 10-week detachment, the Canberra carried out a total of 37 flights of which 20 were directly on the WAMFLEX project; several of the others were concerned with stratospheric humidity measurements.

The meteorological conditions were not as favourable as climatology had led us to expect. Nevertheless marked disturbances were encountered on some of the flights and preliminary analysis indicates that at these times the vertical flux of horizontal momentum is sufficiently large for it to be significant in the energy budget of the hemisphere. It will probably be about another year before all the data have been analysed, and the Canberra results integrated with those of the other participating aircraft.

The Varsity aircraft has primarily been used on co-operative projects with other branches of the Office and through them with the Atomic Energy Research Establishment (AERE), Harwell and the University of Manchester Institute of Science and Technology (UMIST). Flights over the North Sea were made at various times of the year in stable westerly airstreams to determine the atmospheric budget of sulphur dioxide downwind from the industrial areas of England. The equipment used was designed and constructed jointly by the MRF and AERE and described in a paper presented at the WMO Technical Conference on the Observation and Measurement of Air Pollution at Helsinki in August (D. A. Johnson (MRF) and D. M. F. Atkins (AERE)). Results of the flights are being analysed by the Boundary Layer Research Branch. In co-operation with the Cloud Physics Research Branch and UMIST, instruments to measure the electrical properties of the atmosphere have been fitted to the Varsity and a series of flights made (see 'Cloud structure' above).

As will be seen from the photographs (see Plates II–III and front cover), the Hercules aircraft has been extensively modified for its role in meteorological research. The prominent nose boom, about 7 m long, is integrated into the nose of the aircraft to provide a structurally stiff support for instruments mounted on the tip, where, it is thought, the airflow is not disturbed by the presence of the aircraft. The primary function of this instrumentation will be the detection of gusts.

A normal Hercules aircraft has a precipitation radar in the nose; the presence of the nose boom, however, has necessitated the repositioning of this radar in a pod mounted on the top side of the fuselage to the rear of the flight deck. The radar is an E290 3-cm fitted with a 76-cm dish. At present it provides information to the pilot and navigator only with manual control of elevation angle, but plans are in hand to modify the radar such that in certain circumstances the elevation scanning can be automatic and the output will be recorded photographically.

On the rear door is mounted a dropsonde ejector and storage area. This has been specially designed for us by Marshall's of Cambridge and has the capability of accepting sondes up to 127 cm long, 18 cm in diameter and weighing 4½ kg. The sondes, which are at present experimental and manufactured by the Cloud Physics Branch, are 107 cm long, 13 cm in diameter and weigh 3 kg, and are ejected with velocities of about 5 m/s. This is to ensure that they remain clear of the aircraft elevators.

These are the main external changes to the aircraft. Inside the aircraft, the working area for the scientists is located inside a recorder van. This is an acoustically and electrically 'quiet' area which monitors the output of many of the meteorological sensors, and records all instruments, aircraft and meteorological, on magnetic tape. This data-recording system (DRS) has been made to MRF specification by the British Aircraft Corporation, and is a modified version of that made for the MRF Canberra aircraft. Up to 47 channels of

analogue or digital data can be recorded at a maximum sampling rate of 40 Hz and with an overall capability of 640 Hz. In-flight presentation of many of the parameters is available in the van so that the project scientist can make decisions concerning changes in the aircraft flight plan.

MRF still have many minor changes and installations to carry out both in the van and in the fuselage of the aircraft. It is hoped that most of these will be complete early in 1974 so that, after a series of calibration and test flights of the meteorological instruments, the aircraft will be ready for its first major project, namely GATE, in June 1974.

Geophysical fluid dynamics

Studies of fundamental dynamical processes in rapidly rotating fluids bear directly on the development and practical application of theoretical ideas in meteorology and oceanography and on investigations of planetary atmospheres. The Geophysical Fluid Dynamics Laboratory of the Meteorological Office carries out a range of such studies with the main emphasis on laboratory experiments made under reproducible and controllable conditions but with a growing interest in numerical experiments using high-speed electronic computers. Combined laboratory and numerical studies can be particularly valuable, especially in the assessment of the reliability and range of validity of complex numerical schemes and in elucidating certain details which are not readily investigated by laboratory methods.

The main effort during the course of the year has been directed towards the completion of an extensive series of laboratory experiments on 'baroclinic waves', which play a key role in the large-scale circulation of the earth's atmosphere and may, according to recent evidence, also be important in the oceans. There have also been experiments on the structure, stability and other properties of various types of mechanically driven flows in rotating fluids, one group of which has led to a better understanding of the drag forces that arise when the rigid container of the fluid is irregular in shape.

Dynamical and Synoptic Research

Research related to short-range weather forecasting

A large part of the effort of meteorological services throughout the world is devoted to providing weather forecasts for a day or two ahead on a routine basis. These forecasts provide meteorological guidance for a great number of different activities ranging from those of the general public to those of aviation, from near the earth's surface to 10 km or more, and are described in detail on pages 12–26. For many years the Meteorological Office has devoted a substantial effort to investigating methods of improving these short-range forecasts. During 1973 the major effort has once again been focused on those methods which are loosely termed 'numerical weather prediction' in which the physical processes which dominate the behaviour of the atmosphere over periods of a few days are expressed in mathematical terms through the equations of motion, energy and water content. The result is a complex set of partial differential equations which in principle is sufficient to predict the development of the atmospheric patterns of wind, temperature, humidity and rainfall at all heights up to the lower

stratosphere providing that these patterns are well defined initially by the meteorological observations. The equations are highly non-linear and are unlikely to have useful analytical solutions, so that recourse must be made to developing arithmetic methods of integration. About 5000 million arithmetic operations are required in computing a forecast for 24 hours ahead using the most recently developed technique. As the mathematical treatment of the problem is extended so that it resembles more closely the behaviour of the real atmosphere it is likely that the amount of computation will considerably increase.

Current research is concerned with two prediction systems, or models, and these have been described in some detail on page 69 of the *Annual Report* 1972. The first provides predictions of the developing fields of wind, temperature and humidity at 10 equally spaced pressure levels in the vertical, the highest being about 16 km, and rainfall at the ground at an array of points about 300 km apart over most of the northern hemisphere; the second provides similar predictions over a smaller area centred on the U.K., and covering some of North America, the North Atlantic Ocean and Europe at an array of points about 100 km apart. The models are similar in many respects so that much of the research is common to both of them. The first model has been in routine operation since August 1972, while the second, designed to provide more detailed forecasts in the area centered on the U.K., required more refinement before being put into operational use at the end of the year.

Considerable effort has been devoted throughout the year to the devising of more efficient computational schemes. The integration of the equations proceeds stage by stage; the first stage is to predict, from the initial state defined by the synoptic observations, for a short time ahead and the second is to repeat the computational process but this time using the result from the first stage as the starting point. The third stage uses the result from the second stage as the starting point and the process is repeated to give the prediction for many stages ahead. For the finer-mesh model each stage advanced the prediction by about $2\frac{1}{2}$ minutes so that about 600 such steps, each requiring much computation of the same kind, were required in making a 24-hour forecast. The time interval of $2\frac{1}{2}$ minutes is determined by the speed of the fastest-moving waves which are gravity waves. These are present in the atmosphere but are inessential from the point of view of meteorological prediction. A new computational scheme which treats the fast-moving gravity waves in a new and entirely different way has been formulated and allows the time interval to be increased to 12 minutes; although some extra computation is called for at each stage there is an overall gain and the computing time for a 36-hour forecast is reduced from 48 to 12 minutes. The routine forecast is computed twice each day so that the saving of computing time is substantial; research integrations designed to develop the models can also be carried out more frequently. Other changes in the computation of physical processes have led to improved forecasts; in particular, new methods of estimating vertical velocities and stabilities have led to improved predictions of the movement and development of cyclones, of jet-stream speeds and of rainfall. Research is in progress on the more realistic representation of convection, friction and topography, and on improving the technique of using the coarse-mesh model forecast to supply boundary conditions at the edges of the fine-mesh model.

The success of the forecasts depends very much upon the success of the

analysis of the meteorological observations made for the time from which the forecast starts. The analysis defines the complete three-dimensional field of temperature, pressure and humidity on the basis of the observations at the limited number of observation points. The analyses at the 10 levels are necessarily carried out by computer, otherwise much time would be wasted, and many improvements have been made in the computations, especially in the quality control of the observations and the vertical consistency of the analysed fields. The predicted rainfalls depend on the analyses of humidity and strenuous efforts have been made to link humidity in the free atmosphere with meteorological observations near the surface; this problem is becoming urgent since the source of upper-air humidity observations has been reduced by the staged withdrawal of the U.S. ocean weather ships.

The problem of analysis of meteorological fields for extratropical latitudes is well understood, if difficult; analysis in tropical regions presents great difficulties because there are relatively fewer observations on which to base the analysis and because experience of tropical analysis falls far short of that for extratropical regions. The GARP Atlantic Tropical Experiment (GATE) which is to take place in 1974 will provide extensive observations over a limited tropical region and an intensive effort is being made to develop numerical methods of analysis suitable for tropical regions. The technique used for the 10-level models, the fitting of quadric surfaces to the observations near each grid point, will not suffice and the new methods are based on variational and optimal interpolation techniques, the latter having been developed by workers in the U.S.S.R. There will be many different types of observation available during GATE and the analyses must take into account observations from the surface, rawin sondes, radiosondes and pilot-balloon ascents from land and from fixed and moving ships. There will also be upper-wind estimates based on satellite cloud photographs and on the movement of constant-pressure balloons, as well as temperatures based on satellite observations of radiances. The reliability of each type of data is different and the analysis must take account of different weights that should be attached to each type. Considerable experimentation will be needed to establish a sound analysis system.

Good progress has been made with the formulation of a model of the lowest 2 km of the atmosphere which is designed to treat in some detail the physical processes near the ground. This model is intended to lead both to more precise estimates of the exchange processes which interact with the large-scale motions above, and to predictions of small-scale weather elements. The model has 10 levels in the vertical with grid points 10 km apart and an analysis system based on that for the fine-mesh model is being developed. The mathematical problems associated with the preparatory work have proved subtle and stubborn.

Outstation research has continued at an encouraging level into problems of forecasting of that weather which depends very much upon local terrain and exposure. The problems include forecasting rain at Gibraltar, low stratus and fog by using data from a TV mast, sea-breezes and minimum temperatures on concrete surfaces at home stations. Advice on how to tackle these problems and provision of the necessary data in a usable form from the computer are provided by a small team at Headquarters; the team also carries out forecasting research such as on the prediction of visibility at airports, tests of indicators which distinguish between the likelihood of snow and rain, and trials of different

methods of forecasting the warming and moistening of cold air in its passage over a relatively warm sea.

General circulation of the atmosphere

One of the prime tasks of meteorology is to explain the general circulation of the atmosphere. On this depends our ability to understand the climate, to estimate the changes that might follow alterations in the atmospheric composition or changes in the earth's surface features. The importance of this task is recognized by the number of research groups that are devoted to its study in many countries. An understanding promises the extension of the period over which weather forecasts can be useful and determination of the ultimate limit beyond which predictions cannot be expected to have a value. The continuing process of industrialization raises concern about the possibility that world climate may be substantially altered by changes in land use and in the pollution of the atmosphere and the ocean. It is essential to have a thorough understanding of how the atmosphere reacts to such changes if the effects are to be assessed before the event. The development of models to aid in understanding the working of the atmosphere has been a major research task in recent years and the results show that the atmospheric controls and the life cycles of the atmospheric constituents are complex and subtle.

There is general agreement that the problems of the general circulation can best be attacked by an extension of the mathematical models that are proving useful in short-range forecasting. The computations have to be specially designed to take careful account of the physical processes and especially those that may not have an appreciable short-term effect, but which may be dominating when acting over long periods. The ancillary mathematics must provide for computations simulating long periods of atmospheric development without accumulating systematic errors which would nullify the results.

Considerable effort has been devoted during the year to the continued development of the general-circulation models, and progress has been considerably aided by computing power available within the Office. Although the present models, in common with those developed elsewhere, achieve some very convincing simulation of observed climatology, they are not sufficiently sophisticated to answer many of the questions that are posed and their continued development is a prime task.

Much of the research has been carried out using the 5-layer model which has been developed over a number of years; it can now be used to make experimental computations on either a hemispherical or global scale and the execution time of the computation speed is sufficient to allow for simulations of one hundred days atmospheric development. Its performance for different months of the year has been examined and reveals that the simulation of the northern-hemisphere winter is superior to that of both the southern-hemisphere winter and the northern-hemisphere summer, thus raising a variety of problems to be solved to improve the model's overall performance. One of the dominant physical effects to be taken into account is the radiational heating and cooling within the atmosphere. Early versions of the 5-layer model used a simple radiational computing scheme, but the refinement of the model to make it more realistic calls for a more thoroughgoing treatment; considerable effort is being put into this aspect and has led to new computational schemes, including the effects on radiation of the presence of clouds. The transmissivities and

reflectivities of real clouds are not well known from observation and a long series of numerical experiments may be necessary to establish an acceptable representation of radiation.

The examination of sea surface temperature anomalies, which are generally much longer-lasting than atmospheric features of comparable scale, is part of the established routine of the weather forecasts for a month ahead since it is known from observation that the anomalies influence weather on a fairly long time scale. A number of numerical experiments have been carried out using the 5-level general-circulation model in order to trace and understand the influence of oceanic surface temperatures on the development of weather systems; it has been shown that the anomalies in the tropics and subtropics have effects on extensive areas reaching far into mid latitudes and comparison with observation has confirmed the indications from the model. When mid-latitude anomalies are used the indications are less clear and the experiments continue.

A model with 11 layers in the vertical and with about 10 000 grid points covering the entire global surface was introduced during the year; the additional resolution compared with the 5-layer model (with about 5000 grid points) allows a better representation of the physical processes and more accurate computations but the execution time is about an order of magnitude greater. In consequence this model will in the first instance be used for investigations which do not require to simulate the atmosphere for many days; results proceeding from real data indicate that for 7 days the atmospheric changes are followed to an encouraging extent, and the model's capabilities for medium-range forecasting will be investigated.

Tropical regions are of great importance in the general circulation since they contain the atmosphere's principal sources of energy, and the influence of developments in the tropics spreads into middle latitudes within a few days. The development of understanding of the general circulation and of methods of forecasting for more than a day or two ahead has been hampered by a lack of basic understanding of tropical meteorology, and the GARP Atlantic Tropical Experiment (GATE) which is scheduled to take place in the summer of 1974 is designed to provide a period in which extended meteorological observations will be made and our understanding enhanced. The group set up last year and charged with developing mathematical models of atmospheric motions in the tropics has developed a version of the 11-layer model suitable for use for the limited area in which the GATE observations will be made; the model includes special features such as a more elaborate treatment of the energy exchange processes at the sea surface and of the cloud clusters which are of great significance in the tropics. During GATE many observations will be made in addition to the conventional synoptic observations and the task of merging the different kinds of report in a successful analysis scheme has been described above. This analysis may contain features which are not meteorologically important but which may obscure the important meteorological developments especially near the beginning of the forecast period and considerable effort has been devoted to developing computational schemes which eliminate these unwanted features.

GATE is the forerunner of the wider First GARP Global Experiment (FGGE), due to start in 1977, when there will be a period during which intensive meteorological observations will be made on a global basis. As for

GATE the data will be of many different kinds and the problem of assimilating them into a coherent analysis will be basic to success. For FGGE the problem has an added significance for the planners need to know how to allocate the available resources in an optimal way. Experiments have been started using model integrations to indicate regions of observation and analysis in which errors are likely to have the most damaging effect on forecasts. The simulation of the FGGE data input is accomplished by repeating the computation of the forecast for a long period ahead while introducing small changes in the predicted fields from time to time. Preliminary results indicate that the problem of specifying the observational requirements in the tropics is more acute than elsewhere.

The data obtained during GATE require collection and expert validation before being permanently stored and available for scientific use. The Office has undertaken this task in respect of the synoptic-scale data from GATE and staff will be allocated to the task next year. Meanwhile the GATE International Scientific Management Group, which is situated at Bracknell, continues its close association with the Office and will take part in the synoptic-scale data preparation.

The Committee on Meteorological Effects of Stratospheric Aircraft was set up last year in response to the fears expressed in certain quarters that aircraft flying in the stratosphere might emit pollutants that could significantly alter the atmospheric constitution at those levels and even affect the human environment. The Committee's first aim is to direct and co-ordinate research leading to a knowledge of both the natural constitution and variation of the composition of the atmosphere. Without this knowledge it is not possible to assess the effect of man-made emission. Further it aims to assess the changes that might arise from operating aircraft in the stratosphere and their possible meteorological effects. The Comittee directs research into the basic photochemical reactions which determine the densities of the minor constituents at these levels. Laboratory determinations of the reaction rates are contracted out to groups at Oxford and Cambridge Universities while the theoretical computations from the photochemical equations are carried out within the Office. Experimental observations of the densities of the minor constituents are being made by the National Physical Laboratory using aircraft and balloons to carry the instruments. Also a group at Oxford University is developing methods of telemetering the minor constituents from balloons and satellites. Within the Office a mathematical model of the meridional and vertical motions, which includes the main photochemistry of ozone, has been constructed and it shows that the photochemistry must be more complicated than has been thought. A 13-layer model is also being developed, somewhat akin to the 5-layer model of the general atmospheric circulation but with extra vertical resolution in the stratosphere; provision is made for the introduction of the photochemistry of ozone and other minor constituents, based on the current researches on the important reactions. The first extended computation with this model, with simplified representation of radiation and omission of photochemistry, revealed a simulated development which was remarkably like the 'sudden warmings' observed in the upper atmosphere at the end of winter. More sophisticated representations of radiation and photochemical effects are being sought for inclusion in the computations. Research of a similar kind on the effect of flying aircraft in the lower stratosphere is being pursued also in the U.S.A. and France and there is considerable

international co-operation in this work, through communication of new results and reciprocal visits.

Research related to long-range forecasting

The routine issue of weather forecasts for 30 days ahead has continued throughout the year; they are issued at the beginning and middle of each month and are made available to the public through the Press, radio and television. The detailed forecasts along with weather statistics for the relevant period are also made available at a small charge to subscribers who now number about 1800. It is not possible at present to predict on the time scale of the 30-day forecast in the same detail as in the forecast for a day or two ahead and the forecasts do not apply to any particular day. The U.K. is divided into 10 areas and the forecast gives the expected mean monthly anomalies of temperature in one of five categories (equally likely over a long period of years) and of rainfall in one of three categories. The expected sequence of weather events on a broad scale is given along with any expected special features such as abnormal sunshine or snowfall. An experimental forecast for 7 days ahead is made in conjunction with each 30-day forecast and the results are used to afford guidance for the first week of that forecast. The success of the forecasts was similar to that of previous years, with some improvement reflected in the number of forecasts graded excellent or good but the number of poor forecasts remained unchanged.

Research has continued into techniques, mainly statistical, relating the weather over the U.K. to that occurring at an earlier time, usually elsewhere. One which has been developed selects the years in which, say, U.K. temperatures were high and low for a particular month. The pressure fields for each of the three previous months are averaged over the warm months and over the cold months and then subtracted. The charted results show the areas of significant differences and these areas can be examined when forecasting for the next 30 days. The technique has been applied for the 500-mb pressure level for each month and also for 15-day periods. This allows the two halves of the month to be distinguished in cases where there is a notable difference, both as regards temperature and rainfall. The method has been used to pick out the areas with significant surface pressure differences in the month before months of anticyclonic and cyclonic, easterly and westerly, northerly and southerly type.

Research in long-range forecasting requires the ability to process and examine large quantities of data, and a large bank of data has been assembled at Bracknell in a form readily usable by the computer. The data bank contains nearly all the basic data for the last 100 years which is likely to be useful in long-range forecasting and it now also contains many derived data, such as the monthly rainfall over the 10 areas of the forecast classified into quintiles; the bank of derived data is being extended as research proceeds. Much of the derived data available on a monthly basis is now also available for mid month to mid month, allowing the extension of the statistical forecasting rules to these periods. A classification of sea-ice at the season of maximum extent in the Iceland and Baltic areas has proved useful in forecasting for the first six months of the year. The investigations into the effect of sea surface temperature anomalies on weather at a later time were widened by the transference of sea temperature data from punched cards to the data bank. The statistical rules

which follow investigations, and there are many of them, do not necessarily indicate similar forecasts and a monthly post-mortem has been introduced to attempt to find the weights that should be attached to the various rules.

Experimental seasonal forecasts have been produced for each season and the level of success maintained. The potential value of this research is indicated by the increasing number of requests for weather advice on a seasonal time-scale from industry and other sources. Although it is not yet possible to give a seasonal forecast, relevant statistics are provided when available, thus giving some indication of the probability of any bias to cold, warm, wet or dry conditions over the forthcoming season.

Climatic change

There has been a heightening of the interest in climatic change during the year owing to the famines caused in Africa due to unusual droughts, and the fears that mankind could inadvertently alter the present climate through industrial activities. Much publicity has been given to these and other climatic problems in the mass media and there has been an increase also in discussion in scientific journals and at official level. Long-period climatic trends in temperature have been examined using data obtained of the ^{18}O isotope content of an ice core from Camp Century in north-west Greenland published by Danish investigators and also the dates of the wine harvests in France, which extend back to 1484. It has proved difficult to correlate the two where they overlap in time but the wine harvest data confirm the known broad trends in European climate, suggesting that the changes in the past have been on a less than hemispheric scale. Old weather diaries extending back to those of Evelyn, Hook and Blundell have been examined. The study of the past is important in establishing the natural variations in climate and in revealing possible periodicities which might aid in prediction. The importance of very close examination of data is revealed by reported indications of a cooling of the atmosphere which could be at least partially explained by changes in instrumental use rather than any physical change. The importance to mankind of sudden changes of climate on a time-scale of a decade or less was emphasized by the continued drought in the sub-Saharan belt of Africa and the occurrence of the third not cold winter in the U.K. Research continues into the causes of these fluctuations.

Special investigations

Requests for specific meteorological advice are received from government departments, industry and other sources and call for special investigations because the advice cannot be obtained from either a brief scrutiny of data or from the broad lines of research that are being followed in the Office. Many of the requests, such as that for the frequencies of specified cloud bases at an airport, are dealt with rapidly but a number of more general problems require considerable time for their treatment and the advice may be given over a number of years. An important problem in aviation is predicting the occurrence of clear-air turbulence (CAT) and the study continued throughout the year of the experimental data obtained in spring 1972 in a joint investigation carried out with the Royal Aircraft Establishment during which both military and civil pilots were asked to report occurrences of CAT. The usefulness of various methods of forecasting CAT has been evaluated but none of them seems

particularly promising. The flying of Concorde has called for studies of the occurrence of large temperature changes over short distances in the upper troposphere and lower stratosphere, of large vertical wind shears, the avoidance of storm-cloud tops and the effect of meteorological conditions on the extent and severity of the sonic boom, at the ground.

The examination of photographic data of radar cloud observations from Gan and Singapore has been used to indicate the chances of aircraft encounter with tropical storm clouds and analysis of the data continues in order to produce a climatology of tropical weather echoes and to give insight into organization of tropical storms.

Other activities have concerned low-level wind shears in relation to aircraft operations, the problem of optimal averaging of wind measurements for supply to aircraft, pollution problems especially in relation to effluent from chimneys, meteorological factors affecting radio-wave propagation and storm tide surges; also climatological reports and route appreciations for aircraft operation.

Work has continued on the revision of the *Handbook of weather forecasting.*

General Activities of the Research Directorate

The Meteorological Office continued to work closely with a number of national and international bodies which have interests in meteorological research. Scientists from the Office gave advice and undertook investigations as members of a considerable number of committees and working groups of such bodies. The international bodies mainly conerned were the World Meteorological Organization, the International Association of Meteorology and Atmospheric Physics and the Joint Organizing Committee for the Global Atmospheric Research Programme. Mr J. S. Sawyer presided at the Sixth Session of the WMO Commission for Atmospheric Sciences in Versailles in November and the Joint Organizing Committee for GARP met at the Royal Society in London in March. Mr Sawyer is a member.

A WMO-sponsored international symposium was held in May at the Meteorological Office College at Shinfield Park. The subject was the application of numerical weather prediction techniques to weather systems with dimensions from 10 to 1000 km. It was attended by about 100 scientists mainly from overseas.

Very close working arrangements have been established with the International Scientific Management Group for the GARP Atlantic Tropical Experiment. This international group is located at Bracknell and calls upon the Meteorological Office for advice on a wide range of topics. Meteorological Office scientists have attended a number of its planning meetings both at Bracknell and overseas.

Close co-operation and exchange of scientific information have also been maintained in respect of the possible meteorological effects of stratospheric aircraft both with the French 'Groupe d'études sur les conséquences des vols stratosphériques' and the Climatic Impact Program in the U.S.A.

In the United Kingdom close co-operation is maintained with the Natural Environment Research Council and Meteorological Office scientists serve on all

Royal Society committees which are concerned with meteorological problems. There is also increasing collaboration with the Department of the Environment on matters concerning air pollution.

The scientific research of the Office was reviewed by the Meteorological Research Committee and its subcommittees during the course of nine meetings. The Committee also advises on a number of small university research projects which are directly supported by the Meteorological Office in addition to the contracts placed in connection with the study of the effects of aircraft on the stratosphere; these number four together with six placed through the Gassiot Committee of the Royal Society.

During the year two members of university staffs worked in the Office as consultants for short periods. Also six research scientists from overseas carried out research in the Meteorological Office for extended periods during which they were supported by their home institutions or international fellowships.

Professional Training

Training policy in both the professional and management fields is determined and kept under review by the Meteorological Office Training Board which was set up in 1972; 1973 saw the first fruits of its work. New courses for Scientific Officers were instituted at the Meteorological Office College and with the Reading College of Technology there was set up a block-release Higher National Certificate Course to meet especially the needs of Meteorological Office staff serving at remote stations.

The unification of the Scientific Classes within the Civil Service as a whole has led to a need for the training of a Scientific Officer to be geared more closely than hitherto to his level of academic attainment and to his professional experience. Entrants to the grade whether newly recruited or promoted after varying degrees of service in a lesser capacity now take one of three courses at the Meteorological Office College. That which retains for international reasons the historical title 'Scientific Officer Course' is designed to give graduates with high honours in mathematical or physical subjects an overall view of the science of meteorology, an appreciation in practical terms of the many applications of the science in service to the public and a ground knowledge of the functions and methods of working of the various components of the Office. The majority of those attending this course expect in their immediate future to fulfil a role in pure or applied research; they will later play an increasing part in the operational, consultative and administrative work of the Office. For those who will go more immediately into the applied fields including especially weather forecasting, there was developed during 1973 a new training programme centred upon an Applied Meteorology Course. The Applied Meteorology Course is given at graduate level, the minimum normal entry qualification being set at H.N.C. This is the lowest academic level at which, under Civil Service rules, recruits can be accepted directly into the Scientific Officer grade. Existing Scientific Officers with lesser qualifications and those promoted from the Assistant Scientific Officer grade with 'A' levels in mathematics may take the course provided they undergo a concentrated four-week preparation at the College when they are taken through those limited areas of higher mathematics

and physics which are absolutely basic to the comprehension of the theory dealt with during the main course. The Applied Meteorology Course itself is divided into two sections. The first gives in nine weeks a grounding in physical, dynamical and synoptic meteorology with appropriate reference to the principal applications. Subsequently, the course divides according to the nature of the posts which its members will fill. Those going into forecasting receive a further nine weeks' training at the College to be followed by several months of on-the-job training under close supervision at an operational station. A third group of Scientific Officers requiring an entirely different kind of course are those who after a number of years of experience as Assistant Scientific Officers in Synoptic Offices and elsewhere, are promoted to supervisory posts. Under the guidance of the Training Board a new four-week course for SO Supervisors has been developed. The first three of these took place at the College during the year. They have a substantial technical content but also deal with the problems of administration likely to be encountered at the new level and give instruction in the techniques of presentation of weather information.

For purposes of in-house training the Initial Forecasting Course has been largely superseded by the more advanced Applied Meteorology Course. However, the former, which is entered with 'A' levels in mathematics and physics, has been retained as an integral part of the new Sandwich Course which has been instituted in co-operation with the Department of Geophysics at Reading University. This leads to an honours B.Sc. degree in meteorology. The Sandwich Course extends over three and a half years during which attendances at the University alternate with 'industrial' periods spent with the Meteorological Office. The Sandwich Course is particularly attractive for overseas meteorologists who wish to acquire professional training in the practical aspects of weather forecasting in addition to the normal meteorological degree studies.

Other major courses held at the Meteorological Office College cater for staff at successive stages of their professional careers. These changed little in content during the year. However, further steps were taken towards the implementation of the Training Board plans to increase the frequency with which staff undergo refresher training. Amongst the subsidiary courses, the Tropical Meteorology Course and the Mediterranean Meteorology Course continued to attract good attendances notwithstanding the decline in the number of stations staffed overseas by the Meteorological Office. Participation of overseas students in these and in the other courses continues at a high level. The College calendar and syllabuses for all courses are contained in *Meteorological Office Leaflet No. 4* which is published annually and is available on request from the Principal, Meteorological Office College, Shinfield Park, Reading RG2 9AU. The College is fully residential.

Meteorological Office staff are encouraged to take advantage of the part-time courses offered by Technical Colleges and by Colleges of Further Education to improve upon their academic qualifications. The subjects of greatest interest are mathematics, physics and computer science which are taken at 'A' level and lead in many cases to more advanced studies for H.N.C. or to a part-time degree course. To help staff located at remote stations arrangements have been made with the College of Technology in Reading for a block-release course to be provided for Meteorological Office staff requiring an H.N.C. in Mathematics, Statistics and Computing. The course consists of four six-week periods of full-

time study taken at intervals over two years. These are followed by a final examination. In between the six-week periods the tutors keep in working touch with the students by correspondence. The inaugural course began on 1 October 1973. It was attended by 17 suitably qualified Assistant Scientific Officers. These Officers were able to reside at the Meteorological Office College whilst attending their studies in Reading. A further 299 staff members were released for part-time study during the year. Others took advantage of the more limited assistance available under the Further Education Scheme and these included 23 who followed Open University courses.

Five trainee technicians attended the six-months' course in the installation and maintenance of electronic instruments used in Meteorological Offices at home and abroad held at the Technical Training School of the Meteorological Office at Beaufort Park. They had previously received instruction in basic electronics at RAF Sealand. Regular courses in radiosonde operation were attended at the Meteorological Office at Hemsby by staff from Britain and overseas.

Table XVII contains further details of courses completed in 1973 at the three Meteorological Office Training Establishments. Overseas students were sponsored by their own Governments, by the World Meteorological Organization or under British Technical Assistance. In addition to those listed in the Table, 13 overseas students taking degree courses at the University of Reading were sponsored by the Meteorological Office itself as a contribution to the Voluntary Assistance Programme of the World Meteorological Organization. Of the 13, two completed M.Sc. courses, two were awarded M.Phil. degrees in meteorology, and two graduated in physics with meteorology. Four new awards were made in 1973, of which two were for the new Sandwich Course.

Library, Publications and Archives

The National Meteorological Library serves the information needs of the staff of the Meteorological Office. It also meets a large demand for its services from universities, schools, commercial and industrial firms, and the general public.

Accession of published data and literature in the field of meteorology and associated subjects has continued at a high rate. An increasing amount is being acquired in microforms, and the Library now has three viewers for microfiche.

Owing to shortage of shelf space in the Library, most of the large collection of pre-1940 world-wide *Daily Weather Reports* have been moved to Meteorological Office Archives at another location in Bracknell. Requests for retrieval can still be met within 24 hours.

An exchange-of-publications agreement was resumed with the Academia Sinica, Peking, after a six-year loss of contact with the People's Republic of China.

Some figures representative of the work of the Library are given in Table XVI on page 111.

The Editing Section remained responsible for the preparation for printing of most of the official publications of the Office and, throughout the year, co-operated closely with Her Majesty's Stationery Office (HMSO) to ensure

the maintenance of publishing standards recommended by them (as publishers) and by other bodies such as the British Standards Institution. The official publications issued are listed in Appendix III and include the *Meteorological Magazine*, a monthly journal which contains short scientific articles, reviews and items of interest to meteorologists everywhere. There are also two serial publications, *Geophysical Memoirs* and *Scientific Papers*, which provide a means of disseminating widely the results of meteorological research.

The Editing Section is responsible too, in collaboration with HMSO, for dealing with all copyright matters which involve Meteorological Office material, whether published or unpublished.

Meteorological observations in manuscript and other original documents of the Meteorological Office are kept, in accordance with the Public Records Act of 1958, in special repositories (Archives) in Bracknell, Edinburgh and Belfast. The material in these Archives is being consulted by an increasing number of users, both inside and outside the Meteorological Office.

A Working Group on Archives completed its review for the disposal of technical records and made recommendations for retention periods of various machine-readable data banks (on magnetic tape). This review is now being considered.

The Cartographic Drawing Office prepares diagrams for Meteorological Office publications, for internal memoranda, and for reports in scientific journals of research by Meteorological Office staff. It also prepares for various areas of the world the many charts and diagrams which are used as background maps on which meteorological observations are plotted.

J. S. SAWYER
Director of Research

STATISTICS OF THE RESEARCH DIRECTORATE

TABLE XVI—LIBRARY AND ARCHIVES

Library

Publications received: Daily weather reports	15 097
Books, journals, microfilms etc.	8 133
Slides and photographs	411
Individual books, pamphlets, articles, microfilms etc. classified and catalogued	8 810
Publications lent (excluding internal 48-hour loans)	
Daily weather reports	23 662
Books, journals, microfilms etc.	17 639
Slides, photographs, films	5 057
Number of exchange agreements (including 2 new agreements)	377
Number of pages translated by Library translators	1 030
Russian 920, German 107, Polish 3	
Number of pages translated by freelance translators	745
Russian 224, German 214, French 189, Japanese 38, Hungarian 29, Italian 26, Spanish 20, Dutch 3, Polish 2	

Archives

Number of loans	2 300

TABLE XVII—TRAINING

The following figures give details of courses completed during 1973 at the Meteorological Office training establishments at Shinfield Park, Hemsby and Beaufort Park.

	Number of courses	Length of course in weeks	Number of students
Scientific Officers	1	28	16
Initial Forecasting	2	15(16½*)	27
Advanced Forecasting	4	7	42
Extension Course	2	4	19
Senior Meteorologists	1	3	24
Basic Meteorology (Forecaster level)	1	4	11
Meteorological Statistics	1	4	9
Tropical Meteorology	2	3	25
Mediterranean Meteorology	1	3	7
Station Supervisors	3	4	37
Auxiliary and Co-operating Observers	7	1	93
Basic Meteorology (Assistant level)	2	4	10
Initial Assistant	8	4	82
Advanced Assistant	5	6	42
Nautical Officers	1	1	6
Tropical Synoptic Assistant	1	12	7
Radiosonde (Initial)	4	9	12
Radiosonde (Advanced)	2	4	2
Radiosonde Special (Refresher)	3	2	3
Radiosonde Special (GRAW-sonde)	1	2	1
Radiosonde Special (British Antarctic Survey)	1	4	5
Electronics	1	24½	5
Technical Updating	3	2	8
Total			493

* Initial Forecasting 2

Students from the following territories attended courses which terminated during 1973.

	Number of students
Afghanistan	1
Bahamas	1
British Honduras	1
Cyprus	2
East Africa	7
Ghana	2
Greece	1
Hong Kong	3
Jamaica	1
Jordan	2
Liberia	1
Libya	1
Malaysia	5
Malta	3
Netherlands	1
Nigeria	2
Seychelles	8
Singapore	1
South Vietnam	1
Sudan	3
Switzerland	1
Syria	1
Total	49

INTERNATIONAL CO-OPERATION

One hundred years of international co-operation in meteorology culminated in the celebration of the centenary of the World (formerly the International) Meteorological Organization, in Vienna, 4–7 September, and Geneva, 10–12 September. The central ceremony was in the Vienna Academy of Sciences on 7 September, where the first International Meteorological Conference met in 1873. Dr B. J. Mason, Director-General, took part, accompanied by Mr D. G. Harley, Assistant Director (International and Planning). Mr J. S. Sawyer, Director of Research, read a paper at the centenary conference in Vienna and Mr P. J. Meade, Director of Services, did likewise at the Geneva conference. Sir Graham Sutton, former Director-General and IMO Prize-winner, also attended the Geneva conference.

The 25th session of the WMO Executive Committee followed the centenary celebrations in Geneva. Dr B. J. Mason was assisted by Mr D. G. Harley and by Mr H. E. Davies, Secretary of the Meteorological Office, and Mr J. S. Sawyer attended as President of the Commission for Atmospheric Sciences. Major matters considered included the development of World Weather Watch, atmospheric pollution and the United Nations Environment Programme, weather modification, and the planning of the first GARP* Global Experiment due to take place in 1977. The Committee awarded the 18th IMO Prize to Mr J. S. Sawyer jointly with Dr C. H. B. Priestley of Australia.

Three Technical Commissions of WMO met in 1973. The Commission for Instruments and Methods of Observation (CIMO) met in Helsinki in August. The U.K. delegation was led by Mr M. J. Blackwell, Assistant Director (Operational Instrumentation) and included Mr L. Clarkson, Assistant Director (Observational Practices) and Mr A. H. Hooper (Met O 1). Immediately before the CIMO session, a WMO Technical Conference on the Observation and Measurement of Atmospheric Pollution was held, also in Helsinki: Dr J. Brownscombe and Dr E. L. Simmons (both of Met O 15) took part. The Commission for Special Applications of Meteorology and Climatology (CoSAMAC) formed from the earlier Commission for Climatology met in Bad Homburg in October. Mr N. Bradbury, Deputy Director (Observational Services) led the U.K. delegation of Mr R. A. S. Ratcliffe, Assistant Director (Synoptic Climatology) and Mr J. S. Hopkins (Met O 3). The Commission for Atmospheric Sciences (CAS) met in Versailles in November. Mr J. S. Sawyer, President of CAS, was accompanied by Mr P. Goldsmith, Assistant Director (Cloud Physics).

A WMO/IAMAP Symposium on Meoscale Meteorological Systems and Fine Mesh Modelling was held at the Meteorological Office College, Shinfield Park, Reading in May. About 80 overseas visitors and 20 from the United Kingdom took part, and nearly all were accommodated in the College. Participants from the Office included Mr J. S. Sawyer, Dr R. Hide (Head of Met O 21), Mr E. Knighting, Deputy Director (Dynamical Research), and Mr G. R. R. Benwell (Met O 11) who was Symposium Secretary.

The U.K. was represented at one session of a WMO Regional Association, that for Africa held in Geneva in August. Mr G. Needham (Met O 17) was the

---

* A list of abbreviations used in this section, and their meanings, is given on page 120.

principal delegate. U.K. interests in the Region concern primarily those of the island dependencies and the strengthening of the WWW system in Africa.

With the GARP Atlantic Tropical Experiment (GATE) due in mid 1974, there was great activity in preparation for it. The Tropical Experiment Board met in Geneva in March and December, under the chairmanship of Dr B. J. Mason: Mr R. F. Jones, Deputy Director (Physical Research) also took part. A number of meetings on special GATE topics are listed below.

A crucial stage in the major COST project (Co-operation in Science and Technology) for a European Centre for Medium-Term Weather Forecasts was completed when its Convention was signed in Brussels on 11 October. Dr B. J. Mason thereafter attended the first sessions in October and November of the Interim Committee set up to get the Centre quickly under way. Earlier, preparatory meetings in January and September were attended by Mr D. G. Harley and Mr K. R. Brooke (Met O 10) respectively. The other COST projects on meteorological matters continued their progress. Mr M. J. Blackwell went to Brussels for three meetings of the Technical Committee on Meteorology and Oceanography, and Mr G. J. Day (Met O 16) chaired a working-party session at Shinfield Park in November on automatic weather stations.

An informal meeting of the Directors of 16 European Meteorological Services was held at Bracknell on 8 and 9 May. The main topics were the new European Centre, the North Atlantic weather ships and the meteorological satellite project of ESRO. They also met briefly in Geneva in September, and those closely concerned with the ESRO METEOSAT project also met in Paris in February and March. Dr B. J. Mason took part in all of these except the February session, when Mr D. G. Harley represented him. A number of other meetings about METEOSAT matters are listed below.

The planned change-over of the management of the North Atlantic Ocean Stations (weather ships) scheme from ICAO to WMO, and the U.S.A. decision to withdraw their ships from the scheme as from July 1974, led to a number of informal planning meetings. Mr P. J. Meade, Director of Services, attended those in Paris in April and in Geneva at the end of May. He was assisted at the first by Mr L. Nixon (Met O 7) and at the second by Captain G. A. White, Marine Superintendent. Further meetings to draft the new WMO agreement took place in De Bilt, the Netherlands, in July and Geneva in December: both were attended by Mr L. Sugden, Assistant Director (Public Services) and Captain G. A. White, supported by financial and legal advisers.

Other WMO meetings, or joint WMO meetings with other international bodies, in which Meteorological Office staff took part, were as follows:

Subject	*Place and date*	*Attended by*
JOC Study Group Conference on Modelling Aspects of GATE	Tallahassee, U.S.A. January	Mr G. A. Corby, Assistant Director (Dynamical Climatology)
		Mr P. R. Rowntree (Met O 20)
2nd Co-ordination Meeting on Geostationary Meteorological Satellites	Zurich January	Mr D. E. Miller (Met O 19)
ad hoc Working Group on Special Observing Systems for FGGE	Geneva February	Mr G. A. Corby, Assistant Director (Dynamical Climatology)

Subject	*Place and date*	*Attended by*
IMCO Sub-Committee on Safety of Fishing Vessels—13th and 14th Sessions	London February and September	Mr H. C. Shellard (Met O 3) (WMO representative)
Meeting on Implementation of Segments of Main Trunk Circuit Washington/ Bracknell/Paris/Offenbach	Paris February	Mr D. McNaughton (Met O 5) Mr R. Ross (Met O 5)
EC Panel of Experts on Meteorology and Economic and Social Development	Geneva February–March	Dr P. G. F. Caton (Met O 7)
JOC for GARP—8th Session	London March	Mr J. S. Sawyer, Director of Research
Technical Liaison Meeting on Main Trunk Circuit	Paris March	Mr E. J. Bell, Assistant Director (Telecommunications) Mr R. Ross (Met O 5)
EC Panel on Meteorological Aspects of Air Pollution	Geneva April–May	Mr J. S. Sawyer, Director of Research
Joint IOC/WMO Group of Experts on IGOSS Technical Systems (ITECH 1)	Paris May.	Mr G. J. Day (Met O 16)
CIMO Working Group on Accuracy of Measurement	Geneva May	Dr N. E. Rider, Assistant Director (High Atmosphere)
European Weathership Advisory Committee Meeting	The Hague, The Netherlands May	Captain G. A. White (Marine Superintendent)
CAS Working Group on Numerical Weather Prediction	Shinfield Park, Reading May	Mr G. R. R. Benwell (Met O 11)
CBS Working Group on the Global Observing System	Geneva June	Mr J. K. Bannon, Deputy Director (Observational Services)
Co-ordination Meeting with WMO Secretariat on Telecommunications with Iceland	Geneva June	Mr E. J. Bell, Assistant Director (Telecommunications)
Meeting of WMO Advisory Group for the Boundary Layer Sub-Programme for GATE	Geneva June, October	Dr N. Thompson (Porton)
JOC Panel for GATE	Bracknell July	Mr J. S. Sawyer, Director of Research
Aircraft Working Group Meeting for GATE	Oberpfaffenhofen, Munich July	Dr D. G. James (MRF)
GATE Data Management Meeting	Bracknell July and Moscow September	Mr G. A. Howkins (Met O 12)
Joint IOC/WMO Meeting—Planning Group on IGOSS	Geneva August	Mr P. J. Meade, Director of Services
Unesco/WMO Meeting on Hydrological Problems in Europe	Berne August	Mr A. Bleasdale (Met O 8)
CIMO Rocket Sensor Comparisons	Kourou, French Guiana September	Mr R. Almond (Met O 19) Mr G. C. Bridge (Met O 19) Mr M. V. Warboys (Met O 19)
JOC for GARP	Vienna September	Mr J. S. Sawyer, Director of Research
Meeting of Presidents of WMO Technical Commissions	Geneva September	Mr J. S. Sawyer, Director of Research
GATE Radar Working Group, on behalf of ISMG	Montreal October	Dr T. W. Harrold (Met O 8)
Synoptic Scale Sub-Programme Advisory Group for GATE	Bracknell October	Mr A. Gilchrist, Assistant Director (Dynamical Climatology)

WMO/IAMAP Conference on Weather Modification and Working Group on Cloud Physics and Weather Modification	Tashkent October	Mr P. Goldsmith, Assistant Director (Cloud Physics)
CBS Working Group on the Global Data Processing System	Geneva October	Mr G. R. R. Benwell, Assistant Director (Central Forecasting) Mr T. H. Kirk (Met O 2) Mr A. Woodroffe (Met O 12)
CBS Working Group on the Global Telecommunication System	Geneva October/November	Mr E. J. Bell, Assistant Director (Telecommunications) Mr D. McNaughton (Met O 5)
Technical Liaison and Planning Meeting	Frankfurt December	Mr E. J. Bell, Assistant Director (Telecommunications) Mr D. McNaughton (Met O 5)

Attendances, not already listed, at international conferences sponsored wholly or primarily by bodies other than WMO, and other visits abroad were as follows:

Subject	*Place and date*	*Attended by*
NATO Special Programme Panel on Air–Sea Interaction	Brussels January and Marseilles, June	Mr J. S. Sawyer, Director of Research
Liaison with COVOS Group	Paris January	Dr R. J. Murgatroyd (Met O 20)
French/British Conference on the Meteorological Effects of SSTs	Paris January	Mr P. Goldsmith, Assistant Director (Cloud Physics) Dr E. L. Simmons (Met O 15) Dr I. T. N. Jones (Met O 15)
NATO MCMG Study Group Meeting on Special Telecommunications Problems	Brussels January	Mr C. E. Goodison (Met O 5)
ESRO (METEOSAT) Scientific and Advisory Group	Paris January, October and November Toulouse, April	Dr K. H. Stewart (Met O 19)
METEOSAT Working Group for MIEC Software Development	14 meetings in Zurich, Paris, Darmstadt, Rome	Mr D. E. Miller (Met O 19)
ICAO 5th Africa/Indian Ocean RAN Meeting	Rome January–February	Mr S. C. Batcheler (Met O 7)
(Irish) National Committee on Geodesy and Geophysics	Dublin February	Mr W. G. Durbin (Met O 7)
ESRO (METEOSAT) Programme Board	Paris February, March, June, November	Dr K. H. Stewart (Met O 19)
Co-ordinating Group of the Tactical Weather Network—18th Meeting	Wiesbaden March	Mr W. G. Harper (Met O 6) Mr G. A. Cowling (Met O 6)
Faraday Symposium on Fogs and Smokes	Swansea March	Mr P. Goldsmith, Assistant Director (Cloud Physics) Dr W. T. Roach (Met O 15)
International Symposium on Moist Grain Storage	Paris March	Mr C. V. Smith (Met O 8)
COVOS/COMESA Symposium on the Meteorological Effects of Stratospheric Aircraft	Paris March	Dr E. L. Simmons (Met O 15) Dr R. J. Murgatroyd (Met O 20) Dr A. F. Tuck (Met O 20) Mr P. Graystone (Met O 20) Mr R. L. Newson (Met O 20) Dr S. R. Mattingly (Met O 20)
13th International Technical and Scientific Meeting on Space	Rome March	Dr B. J. Mason, Director-General

Subject	*Place and date*	*Attended by*
Joint Cardington/AFCRL Atmospheric Boundary Layer Experiment	Boston, Mass. March–April	Dr C. J. Readings (Cardington)
	Hallock, Minnesota August—September	Mr A. J. Marks (Cardington)
2nd Conference on 1956 ICAO Danish and Icelandic Joint Financing Agreement	Paris March–April	Mr L. R. Nixon (Met O 7)
Spectrophotometer Intercomparison	Arosa, Switzerland April	Mr J. H. Convery (Met O 19)
SHAPE Meteorological Committee—16th Meeting	Rome April	Mr D. W. Tann (Met O 6) Mr C. E. Goodison (Met O 5)
NATO MCMG Working Groups on Weather Plans and Weather Communications—37th/38th Meetings	Rome April and Copenhagen September	Mr D. W. Tann (Met O 6) Mr C. E. Goodison (Met O 5) Mr J. C. Gordon (Met O 6)
NATO Sub-Group VI Meeting of the MCMG Working Group on Weather Centres	Rome April	Mr D. W. Tann (Met O 6)
Meteorological Panel (Panel XII) of NATO Group AC/225	Brussels April	Mr C. R. Flood (Met O 6)
American Geophysical Union Annual Meeting	Washington April	Dr P. J. Mason (Met O 21)
IAMAP Commission on Atmospheric Chemistry and Global Pollution Conference on Trace Gases	Mainz April	Mr P. Goldsmith, Assistant Director (Cloud Physics)
AGARD/NATO Flight Mechanics' Panel Symposium on 'Flight in Turbulence'	Woburn Abbey, Beds. May	Mr J. Briggs, Assistant Director (Special Investigations) Mr S. G. Cornford (Met O 9)
AFCENT Meteorological Committee—21st Meeting	Brunssum, The Netherlands May	Mr W. G. Harper (Met O 6) Mr G. A. Cowling (Met O 6)
International Radiation Commission Working Group	Lille, May and Paris, September	Dr G. E. Hunt (Met O 20)
NATO/CCMS Panel on Air Pollution Modeling	Oberursel, West Germany May	Dr F. B. Smith (Met O 14)
CNES Symposium — Meteorological Satellites	Paris May	Dr K. H. Stewart (Met O 19) Mr R. D. Hunt (Met O 19)
Committee on Space Research/ICSU	Konstanz, West Germany May–June	Dr N. E. Rider, Assistant Director (High Atmosphere)
NATO MCMG—30th Meeting	Brussels June	Mr P. J. Meade, Director of Services Mr E. Evans, Assistant Director (Defence Services) Mr D. W. Tann (Met O 6)
Working Group on JONSIS	Hamburg June	Mr M. J. Blackwell, Assistant Director (Operational Instrumentation)
5th Conference on Laser Radar Studies of the Atmosphere	Williamsburg, U.S.A. June	Mr R. E. W. Pettifer (Met O 19)
NATO MAS NBC Operational Procedures Inter-Service Working Party	Brussels June	Mr K. Bryant (Met O 6) Mr G. A. Samuel (Met O 6)
ICAO Informal Meteorological Meeting on International General Aviation	Vienna June	Mr C. H. Hinkel (Met O 7)
VTPR Workshop	Washington July	Mr B. R. May (Met O 19)

Subject	*Place and date*	*Attended by*
NATO Panel VII Study Group Meeting	London July	Mr K. Bryant (Met O 6) Mr G. A. Samuel (Met O 6)
4th Meeting of the ICAO Technical Panel on SST Operations (SST Panel)	Montreal July	Mr A. Johnson (Met O 7)
University of London Symposium on 'Drought in Africa'	London July	Mr A. F. Jenkinson (Met O 13)
CODATA Symposium on 'Man–Machine Communication' for Scientific Data Handling	Freiburg, West Germany July	Dr A. J. Gadd (Met O 11)
NOAA Workshop on use of Satellite Data	Suitland, Maryland July	Mr C. R. Flood (Met O 2)
Summer School on Orographic Effects in Meteorology	Venice August	Mr C. G. Collier (Met O 8)
International Astronomical Union Extraordinary General Assembly	Torun, Poland September	Dr R. Hide (Head of Met O 21)
SHAPE Meteorological Committee Working Group for ACEWEX—11th Meeting	Naples September	Mr W. G. Durbin (Met O 6) Mr G. A. Cowling (Met O 6)
NATO Sub-Group VII Meeting of MCMG — Working Group on Meteorological Satellites	Paris September	Mr J. C. Gordon (Met O 6)
ICAO Asia/Pacific RAN Meeting	Honolulu September	Mr S. C. Batcheler (Met O 7)
European Geophysical Society Conference	Zurich September	Dr G. E. Hunt (Met O 20)
OECD Co-operative Technical Programme on the Transport of Air Pollutants	Lillehammer, Norway September	Dr F. B. Smith (Met O 14)
International Standards Organization Sub-Committee ISO/TC20/SC6 'Standard Atmosphere'—4th Meeting	Paris October	Mr J. Briggs, Assistant Director (Special Investigations)
IUCRM Colloquium on Fine Scale Structure of Precipitation and EM Propagation	Nice October	Mr J. Briggs, Assistant Director (Special Investigations)
Meeting of the ABCA Armies Quadripartite Working Group on Meteorology	Larkhill October	Mr K. Bryant (Met O 6)
20th SPATC Meeting	Fiji October	Mr G. Needham (Met O 17)
Liaison on management of new WWW station at Tarawa	Tarawa, Gilbert Isles and Wellington, N.Z. November	Mr G. Needham (Met O 17)
Conference on the CIAP Monographs on the Natural and Perturbed Stratosphere	Boulder, Colorado October	Mr P. Graystone (Met O 20)
IUCRM Symposium	Nice October	Dr T. W. Harrold (Met O 8)
8th International Conference on Nucleation (ICCP/IAMAP)	Leningrad October	Mr P. Goldsmith, Assistant Director (Cloud Physics)
AFCENT Meteorological Sub-Committee for 2ATAF and NORTHAG—13th Meeting	Rheindahlen November	Mr W. G. Durbin (Met O 6) Mr G. A. Cowling (Met O 6) Mr W. D. Hyde (Met O 6)
CENTO Regional Meteorological Group—3rd Meeting	Ankara November	Mr D. W. Tann (Met O 6)
Symposium on Solar Radiation Measurements and Instrumentation	Rockville, U.S.A. November	Mr R. H. Collingbourne (Met O 1)

Subject	*Place and date*	*Attended by*
ESRO (METEOSAT) Programme Board	Paris November	Dr B. J. Mason, Director-General
9th Meeting of the MOTNE Regional Planning Group of ICAO	Paris December	Mr C. H. Hinkel (Met O 7)
NATO Working Party on International Exercises	Paris December	Mr K. Bryant (Met O 6)

No new releases of staff to take up international appointments overseas were made during 1973.

The following staff returned to the Office from appointments overseas:

Mr D. Black	Scientific Officer	from Zambia
Mr G. V. Clark	Higher Scientific Officer	from East African Community
Mr H. G. Hills	Scientific Officer	from Zambia
Mr J. D. Lowry	Scientific Officer	from Zambia
Mr H. Macdonald	Assistant Scientific Officer	from Zambia
Mr J. M. Mersom	Assistant Scientific Officer	from British Antarctic Survey, Falkland Islands

List of abbreviations used in this section

ABCA	—	America, Britain, Canada, Australia
ACEWEX	—	Allied Command Europe, Exchange of Weather Information
AFCENT	—	Allied Forces Central Europe
AFCRL	—	Air Force Cambridge (Massachusetts) Research Laboratories
AGARD	—	Advisory Group for Aerospace Research and Development
ATAF	—	Allied Tactical Air Force
CAS	—	Commission for Atmospheric Sciences
CBS	—	Commission for Basic Systems
CCMS	—	Committee on the Challenges of Modern Society
CENTO	—	Central Treaty Organization
CIAP	—	Climatic Impact Assessment Programme
CIMO	—	Commission for Instruments and Methods of Observation
CNES	—	Centre National D'Études Spatiales
CODATA	—	Committee on Data for Science and Technology
COMESA	—	Committee on the Meteorological Effects of Stratospheric Aircraft
COST	—	European Co-operation in Science and Technology
COVOS	—	Le Groupe d'études sur les Conséquences des Vols Stratosphériques
EC	—	Executive Committee
EM	—	Electro-Magnetic
ESRO	—	European Space Research Organization
FGGE	—	First GARP Global Experiment
GARP	—	Global Atmospheric Research Programme
GATE	—	GARP Atlantic Tropical Experiment
GDPS	—	Global Data Processing Systems
GOS	—	Global Observing Systems
IAMAP	—	International Association of Meteorology and Atmospheric Physics
ICAO	—	International Civil Aviation Organization
ICCP	—	International Commission for Cloud Physics
ICSU	—	International Council of Scientific Unions
IGOSS	—	Integrated Global Ocean Station System
IMCO	—	Inter-Governmental Maritime Consultative Organization
IOC	—	Inter-Governmental Oceanographic Commission
ISMG	—	International Scientific and Management Group
ISO	—	International Organization for Standardization
IUCRM	—	Inter-Union Commission for Radio Meteorology
JOC	—	Joint Organizing Committee (for GARP)
JONSIS	—	Joint North Sea Information Systems
MAS	—	Military Agency for Standardization
MCMG	—	Military Committee Meteorological Group
METEOSAT	—	Meteorological Satellite
MIEC	—	Meteorological Information Extraction Centre
MOTNE	—	Meteorological Operational Telecommunication Network Europe
NATO	—	North Atlantic Treaty Organization
NBC	—	Nuclear, Biological, Chemical
NOAA	—	National Oceanic and Atmospheric Administration (formerly ESSA)
NORTHAG	—	Northern Army Group Central Europe
OECD	—	Organization for Economic Co-operation and Development
RA	—	Regional Association (WMO)
RAN	—	Regional Air Navigation
SHAPE	—	Supreme Headquarters Allied Powers in Europe
SPATC	—	South Pacific Air Transport Council
SST	—	Supersonic Transport
Unesco	—	United Nations Educational, Scientific and Cultural Organizat on
VTPR	—	Vertical Temperature Profile Radiometer
WMO	—	World Meteorological Organization
WWW	—	World Weather Watch

STAFF

GENERAL

The names of the principal officers of the Meteorological Office are listed on pages xi–xiii and the organization of the Office is shown in the diagram on page xiv. At the end of 1973 the total number of posts of all grades was 3689, a decrease of 2 over the year. The actual strength at the end of the year was made up as follows:

Deputy Secretary	1
Under Secretary	2
Science Group	
Deputy Chief Scientific Officers	8
Senior Principal Scientific Officers	28
Principal Scientific Officers	97
Senior Scientific Officers	285
Higher Scientific Officers	492
Scientific Officers	517
Assistant Scientific Officers	1017
Administration Group	
Assistant Secretary	1
Principal	1
Executive Grades	26
Clerical Grades	148
Marine Staff	
Marine Superintendent	1
Nautical Officer Grades	10
Ocean Weather Ships and Base	
Officers and non-industrial grades	96
Crew	100
Professional Engineer Staff	
Superintending Engineer	1
Principal Professional and Technology Officer	1
Professional and Technology Officer Grade I	3
Professional and Technology Officer Grade II	4
Technical and Signals Grades	316
Typing and miscellaneous non-industrial grades	155
Industrial employees	96
Locally entered staff and employees overseas	144

It has been a very successful year for the recruitment of graduates into the Office at Scientific Officer level and above and over 30 graduates, mostly very well qualified, have been appointed. Unfortunately recruitment of support staff has not been so successful. It has not kept pace with the rate of resignation and the Office has suffered from an increasing shortage of Assistant Scientific Officers.

Nine college-based Sandwich Course students were accepted during the year for their supervised industrial training periods, and 11 undergraduates were employed during the long vacation. These students made a useful contribution to the work of the Office and several expressed a wish to join the Office after graduation. Two vacation consultants from universities gave valuable support in specialized research fields during the summer.

There has been an increase in the effort devoted to management training and almost 100 scientific staff attended courses provided by the Civil Service College and similar training centres. There was also a modest increase in effort devoted to management training from internal sources; and in preparation for the introduction of Job Appraisal Reviews in 1974 nearly 1000 staff received appropriate training on 1-day courses.

HONOURS AND DISTINCTIONS

In the New Year Honours List the Director-General was appointed Companion of the Bath.

The following appointments to the Imperial Service Order were announced:
Mr R. K. Pilsbury (retired) in the New Year Honours List.
Mr H. B. Rowles in the Birthday Honours List.

The International Meteorological Organization Prize was awarded by the World Meteorological Organization to Mr J. S. Sawyer jointly with Dr C. H. B. Priestley of Australia.

The L. G. Groves Memorial Prize for Meteorology was awarded to Mr P. Goldsmith.

The FitzRoy Prize was awarded to Mr D. M. Houghton by the Royal Meteorological Society.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

AANENSEN, C. J. M., M.Sc.; The use of Nimbus 4 radiance and radiosonde data in the construction of stratospheric contour charts. *Q J R Met Soc, London,* **99,** 1973, pp. 657–668.

ACHESON, D. J., Ph.D.; Hydromagnetic wavelike instabilities in a rapidly rotating stratified fluid. *J Fluid Mech, London,* **61,** 1973, pp. 609–624.

ACHESON, D. J., Ph.D.; Valve effect of inhomogeneities on anisotropic wave propagation. *J Fluid Mech, London,* **58,** 1973, pp. 27–37.

ACHESON, D. J., Ph.D. and HIDE, R., Sc.D., F.R.S.; Hydromagnetics of rotating fluids. *Rep Prog Phys, London,* **36,** 1973, pp. 159–221.

ALDERSON, C., *see* HOWKINS, G. A., MCNAUGHTON, D. and ALDERSON, C.

AXFORD, D. N., M.A., M.Sc., A.I.E.E.; On an observation of turbulent waves on the tropopause surface. *Q J R Met Soc, London,* **99,** 1973, pp. 438–449.

AXFORD, D. N., *see* BROWNING, K. A., BRYANT, G. W., STARR, J. R. and AXFORD, D. N.

BADER, M., M.Sc.; A late April snowfall in southern England. *Weather, London,* **28,** 1973, pp. 251–257.

BAILEY, V., *see* SMITH, L. P., COCHRANE, J. and BAILEY, V.

BANNISTER, J. E.; Support vessels off Iceland during September and October 1972. *Mar Obsr, London,* **43,** 1973, pp. 81–86.

BLACKALL, R. M., B.Sc.; Warming of the lower troposphere by the sea. *Met Mag, London,* **102,** 1973, pp. 65–73.

BLACKWELL, M. J., M.A. and CLARKSON, L. S., M.Sc.; Rule for reading the rain measure. Reply to letter by MEADEN, G. T. (*Met Mag, London,* **102,** 1973, pp. 94–95). *Met Mag, London,* **102,** 1973, p. 95.

BLACKWELL, M. J., M.A. and SANDS, K. J. T.; Offshore telemetering buoy for real-time monitoring of sensor performance. Geneva, World Meteorological Organization. Reports on Marine Science Affairs, No. 7, Geneva, 1973, pp. 199–201.

BLEASDALE, A., B.A., B.Sc.; Meteorological contributions to operational hydrological forecasting in the United Kingdom. *Met Mag, London,* **102,** 1973, pp. 298–308.

BLEASDALE, A., B.A., B.Sc.; Statistical problems in practical hydrometeorology. *The Statistician, London,* **22,** 1973, pp. 103–123.

BLEASDALE, A., B.A., B.Sc. and CHAN, Y. K.; Orographic influences on the distribution of precipitation. Geneva, World Meteorological Organization. Distribution of precipitation in mountainous areas, Vol. II, Geneva, 1972, pp. 322–333.

BOOTH, B. J.; A simplified snow predictor. *Met Mag, London,* **102,** 1973, pp. 332–340.

BRADBURY, T. A. M.; Glider flight in the lower stratosphere above cumulonimbus clouds. *Met Mag, London,* **102,** 1973, pp. 110–120.

BRIDGE, G. C.; A comparison of geostrophic and rocket winds at stratospheric levels, measured from a small network of rocket sounding stations. *Met Mag, London,* **102,** 1973, pp. 205–211.

BRIDGE, G. C. and MASON, B.D., B.Sc. *in* HAMILTON, R. A., O.B.E., MASON, B.D. and BRIDGE, G. C.; A climatology of the stratosphere over north-west Europe. *Geophys Mem, London,* **17,** No. 119, 1973.

BROOKES, H. T.; Halo display at RAF Gütersloh. *Met Mag, London,* **102,** 1973, pp. 279–280.

BROWNING, K. A., Ph.D., D.I.C. *et alii*; Capabilities of radar, sodar and lidar for measuring the structure and motion of the stably stratified atmosphere. *Boundary Layer Met, Dordrecht,* **5,** 1973, pp. 195–200.

BROWNING, K. A., Ph.D., D.I.C., BRYANT, G. W., Ph.D., STARR, J. R., Ph.D., D.I.C. and AXFORD, D. N., M.A., M.Sc., A.I.E.E.; Air motion within Kelvin-Helmholtz billows determined from simultaneous Doppler radar and aircraft measurements. *Q J R Met Soc, London,* **99,** 1973, pp. 608–618.

BROWNING, K. A., Ph.D., D.I.C., HARDMAN, M. E., B.Sc., HARROLD, T. W., Ph.D., D.I.C. and PARDOE, C. W., B.Sc.; The structure of rainbands within a mid-latitude depression. *Q J R Met Soc, London,* **99,** 1973, pp. 215–231.

BROWNING, K. A. Ph.D., D.I.C. and PARDOE, C. W., B.Sc.; Structure of low-level jet streams ahead of mid-latitude cold fronts. *Q J R Met Soc, London,* **99,** 1973, pp. 619–638.

BROWNING, K. A., Ph.D., D.I.C., STARR, J. R., Ph.D., D.I.C. and WHYMAN, A. J.; The structure of an inversion above a convective boundary layer as observed using high-power pulsed Doppler radar. *Boundary Layer Met, Dordrecht*, **4**, 1973, pp. 91–111.

BROWNING, K. A., *see* READINGS, C. J., GOLTON, E. and BROWNING, K. A.

BROWNING, K. A., *see* STARR, J. R. and BROWNING, K. A.

BRYANT, G. W., *see* BROWNING, K. A., BRYANT, G. W., STARR, J. R. and AXFORD, D. N.

CARRUTHERS, G. P., MAY, B. R., B.Sc., MILLER, D. E., B.A. and STEWART, K. H., Ph.D.; Some current work on meteorological satellites. *Met Mag, London*, **102**, 1973, pp. 258–265.

CARRUTHERS, G. P. and ROBINSON, G. A. *in* HARRIES, J. E. *et alii*; Measurements of the submillimetre stratospheric emission spectrum from a balloon platform. *Infrared Physics, London*, **13**, 1973, pp. 149–155.

CARSON, D. J., Ph.D.; A model for the development of a convectively unstable boundary layer. *Q J R Met Soc, London*, **99**, 1973, pp. 774–775.

CARSON, D. J., Ph.D. and SMITH, F. B., Ph.D.; The Leipzig wind profile and the boundary layer wind-stress relationships. *Q J R Met Soc, London*, **99**, 1973, pp. 171–177.

CATON, P. G. F., *see* JACKSON, F. C. and CATON, P. G. F.

CLARKSON, L. S., M.Sc.; The performance of a mast-top rain-gauge in the field. *Met Mag, London*, **102**, 1973, pp. 82–90.

CLARKSON, L. S., M.Sc., *see* BLACKWELL, M. J. and CLARKSON, L. S.

COCHRANE, J.; Climatic limits for viticulture in England and Wales. *J Engl Vineyards Assn, London*, No. 6, July 1972.

COCHRANE, J., *see* SMITH, L. P., COCHRANE, J. and BAILEY, V.

COLLINGBOURNE, R. H., M.Sc., D.I.C.; Radio-activity fallout and secular effects in atmospheric electricity. Comment on a paper by PIERCE, E. T. (*J Geophys Res, Richmond, Va*, **77**, 1972, pp. 482–487). *J Geophys Res, Richmond, Va*, **77**, 1972, pp. 6634–6636.

COLLISON, P., B.Sc. and RATCLIFFE, R. A. S., M.A. *in* LAMB, H. H., COLLISON, P. and RATCLIFFE, R. A. S.; Northern hemisphere monthly and annual mean-sea-level pressure distribution for 1951–66, and changes of pressure and temperature compared with those of 1900–39. *Geophys Mem, London*, **16**, No. 118, 1973.

CORBY, G. A., *see* GILCHRIST, A., CORBY, G. A. and NEWSON, R. L.

CORNFORD, S. G., M.Sc. and SPAVINS, C. S.; Some measurements of cumulonimbus tops in the pre-monsoon season in north-east India. *Met Mag, London*, **102**, 1973, pp. 314–332.

CRADDOCK, J. M., M.A.; The place of the amateur in meteorology today. *Weather, London*, **28**, 1973, pp. 90–101.

CRADDOCK, J. M., M.A.; A plan for the determination of the large-scale weather patterns during the period 1493–1860. *Met Mag, London*, **102**, 1973, pp. 217–224.

CRADDOCK, J. M., M.A.; Problems and prospects for eigenvector analysis in meteorology. *The Statistician, London*, **22**, 1973, pp. 133–144.

CULLEN, M. J. P., B.A.; A simple finite element method for meteorological problems. *J Inst Math & its Appl, London*, **11**, 1973, pp. 15–31.

DIVER, A.; 'Sea breeze' over central England. *Sailpl Gliding, London*, **24**, 1973, pp. 38–40.

DOUGLAS, H. A., B.Sc. and MASON, P. J., Ph.D.; Thermal convection in a large rotating fluid annulus: some effects of varying the aspect ratio. *J Atmos Sci, Lancaster, Pa*, **30**, 1973, pp. 1124–1134.

DUTTON, M. J., B.Sc.; Errors in 48-hour movement and development of computer-forecast 500-millibar troughs and ridges: American and British models compared. *Met Mag, London*, **102**, 1973, pp. 97–109.

ENGLISH, E. J., B.Sc.; An objective method of calculating areal rainfall. *Met Mag, London*, **102**, 1973, pp. 292–298.

ENGLISH, E. J., *see* HARROLD, T. W., ENGLISH, E. J. and NICHOLASS, C. A.

ENGLISH, E. J., *see* HARROLD, T. W., ENGLISH, E. J. and NICHOLASS, C. A.

FARMER, SHEILA A., B.Sc.; A note on the long term effects on the atmosphere of sea surface temperature anomalies in the North Pacific Ocean. *Weather, London*, **28**, 1973, pp. 102–105.

FLOOD, C. R., B.A., *in* WRIGHT, P. B. and FLOOD, C. R.; A method of assessing long-range forecasts. *Weather, London*, **28**, 1973, pp. 178–187.

FOLLAND, C. K., B.Sc., Grad.Inst.P.; Low-power humidity sensor for unattended use on buoys. Geneva, World Meteorological Organization. Reports on Marine Science Affairs, No. 7, Geneva, 1973, pp. 186–198.

FOOT, J. S., *see* GOLDSMITH, P., TUCK, A. F., FOOT, J. S., SIMMONS, E. L. and NEWSON, R. L.

GARROD, M. [P.]; A glider pilot's guide to wave forecasting—(Part 1). *Sailpl Gliding, London*, **24**, 1973, pp. 406–407.

GARROD, M. [P.]; In search of Elysian wave. *Sailpl Gliding, London*, **24**, 1973, pp. 6–8.

GILCHRIST, A., M.A., CORBY, G. A., B.Sc. and NEWSON, R. L., B.A.; A numerical experiment using a general circulation model of the atmosphere. *Q J R Met Soc, London*, **99**, 1973, pp. 2–34.

GLOYNE, R. W., Ph.D.; The 'growing season' at Eskdalemuir Observatory, Dumfriesshire. *Met Mag, London*, **102**, 1973, pp. 174–178.

GLOYNE, R. W., Ph.D. and MCKERRELL, ELIZABETH A.; Number of days of air frost in the winter months in Scotland in relation to the mean air temperature—on a period-average basis, and for individual years at selected stations. *Met Mag, London*, **102**, 1973, pp. 272–277.

GOLDSMITH, P., M.A., TUCK, A. F., Ph.D., FOOT, J. S., Ph.D., SIMMONS, E. L., Ph.D. and NEWSON, R. L., B.A.; Nitrogen oxides, nuclear weapon testing, Concorde and stratospheric ozone. *Nature, London*, **244**, 1973, pp. 545–551.

GRANT, K., B.A.; The gales of 2 April 1973. *Weather, London*, **28**, 1973, p. 400.

GRAYSTONE, P., B.A.; Experiments with a two-dimensional stratospheric model using mean motions and diffusion coefficients. Paris, Centre National de la Recherche Scientifique, Séminaire franco-britannique sur les conséquences des vols stratosphériques. COVOS/COMESA, Paris, 22–23 March 1973. Paris, 1973, Section VII.

HARDMAN, M. E., *see* BROWNING, K. A., HARDMAN, M. E., HARROLD, T. W. and PARDOE, C. W.

HARLEY, D. G., B.Sc.; British architects of the International Meteorological System. *Met Mag, London*, **102**, 1973, pp. 249–257.

HARLEY, D. G., B.Sc.; IMO, WMO and 100 years of interdependence. *Weather, London*, **28**, 1973, pp. 372–377.

HARROLD, T. W., Ph.D., D.I.C.; Mechanisms influencing the distribution of precipitation within baroclinic disturbances. *Q J R Met Soc, London*, **99**, 1973, pp. 232–251.

HARROLD, T. W., *see* BROWNING, K. A., HARDMAN, M. E., HARROLD, T. W. and PARDOE, C. W.

HARROLD, T. W., Ph.D., D.I.C., BUSSELL, R. and GRINSTED, W. A.; The Dee Weather Radar Project. Geneva, World Meteorological Organization. Distribution of precipitation in mountainous areas, Vol. II. Geneva, 1972, pp. 47–61.

HARROLD, T. W., Ph.D., D.I.C., ENGLISH, E. J., B.Sc. and NICHOLASS, C. A. B.Sc.; The Dee Weather Radar Project: the measurement of area precipitation using radar. *Weather, London*, **28**, 1973, pp. 332–338.

HARROLD, T. W., Ph.D., D.I.C., ENGLISH, E. J., B.Sc. and NICHOLASS, C. A., B.Sc.; Some results of radar measurements of precipitation in a hilly region. *Proc 15th Radar Met Conf, Champaign-Urbana, Ill., Oct.* 1972, Boston, Mass, American Meteorological Society, 1972, pp. 161–166.

HAWSON, C. L., B.A.; SI units in the Meteorological Office. Comment on a paper by LUMB, F. E. (*Met Mag, London*, **101**, 1972, pp. 366–368). *Met Mag, London*, **102**, 1973, pp. 155–156.

HEIGHES, J. M.; Modifying hurricanes. *New Scientist, London*, **59**, 1973, p. 711. Comment on: Thin layers could slow down hurricanes, *New Scientist, London*, **59**, 1973, p. 503.

HIDE, R., Sc.D., F.R.S.; Jupiter's great red spot revisited. *Phys Earth Planet Interiors, Amsterdam*, **6**, 1972, p. 99.

HIDE, R., *see* ACHESON, D. J. and HIDE, R.

HOLGATE, H. T. D., B.A.; Rainfall forecasting for river authorities. *Met Mag, London*, **102**, 1973, pp. 33–48.

HOUGHTON, D. [M.], M.Sc.; The weather men. London, Ginn and Co. Ltd, 1972.

HOWKINS, G. A., M.B.E., B.Sc.; The Meteorological Office 360/195 computing system. *Met Mag, London*, **102**, 1973, pp. 5–14.

HOWKINS, G. A., M.B.E., B.Sc., MCNAUGHTON, D. and ALDERSON, C.; The Richardson Wing. *Met Mag, London*, **102**, 1973, pp. 2–5.

HUNT, G. E., Ph.D., F.I.M.A.; Computational modelling of radiative transfer processes of the lower atmosphere. *J Quant Spectrosc & Radiat Transfer, London*, **12**, 1972, pp. 63–70.

HUNT, G. E., Ph.D., F.I.M.A.; Formation of spectral lines in planetary atmosphere IV. Theoretical evidence for structure of the Jovian clouds from spectroscopic observations of methane and hydrogen quadrupole lines. *Icarus, New York*, **18,** 1973, pp. 637–648.

HUNT, G. E., Ph.D., F.I.M.A., *in* TAYLOR, F. W. and HUNT, G. E.; The infrared spectrum of Jupiter: structure and radiative properties of the clouds. Boston, Mass, American Meteorological Society, Conference on Atmospheric Radiation, Aug. 1972, Fort Collins, Col., 1972, Boston, Mass, 1972.

HUNT, G. E., Ph.D., F.I.M.A.; Interpretation of hydrogen quadrupole and methane observations of Jupiter and the radiative properties of the visible clouds. *Mon Not R Astr Soc, London*, **161,** 1973, pp. 347–363.

HUNT, G. E., Ph.D., F.I.M.A.; Line formation in a Jovian atmosphere. Boston, Mass, American Meteorological Society, Conference on Atmospheric Radiation, Aug. 1972, Fort Collins, Col., 1972, Boston, Mass, 1972.

HUNT, G. E., Ph.D., F.I.M.A.; Radiative properties of terrestrial clouds at visible and infra-red thermal window wavelengths. *Q J R Met Soc, London*, **99,** 1973, pp. 346–369.

HUNT, G. E., Ph.D., F.I.M.A.; There is evidence for two scattering layers in the Venus atmosphere. *J Quant Spectrosc & Radiat Transfer, London*, **13,** 1973, pp. 465–466.

HUNT, G. E., Ph.D., F.I.M.A.; There is no evidence for ice caps on Mercury. *The Observatory, London*, **92,** 1972, p. 16.

HUNT, G. E., Ph.D., F.I.M.A., *in* MARGOLIS, J. S. and HUNT, G. E.; On the level of H_2 quadrupole absorption in the Jovian atmosphere. *Icarus, New York*, **18,** 1973, pp. 593–598.

HUNT, G. E., Ph.D., F.I.M.A. and BARTLETT, J. T.; The lower Venus atmosphere. *Endeavour, London*, **32,** 1973, pp. 39–43.

HUNT, G. E., Ph.D., F.I.M.A. and MARGOLIS, J. S.; Formation of spectral lines in planetary atmospheres. V. Collision narrowed profiles of quadrupole lines in hydrogen atmospheres. *J Quant Spectrosc & Radiat Transfer, London*, **13,** 1973, pp. 417–426.

JACOBS, L., M.A., M.Sc.; A short history of the former homes of the Meteorological Office. *Met Mag, London*, **102,** 1973, pp. 48–50.

JACKSON, F. C. and CATON, P. G. F., Ph.D.; Some meteorological effects on gun and shell detonation noise at distances ¾ to 2½ miles from source. *Met Mag, London*, **102,** 1973, pp. 229–239.

JEFFREY, G. H., *see* SMITH, F. B. and JEFFREY, G. H.

JONAS, P. R., Ph.D. and TABONY, R. C., B.Sc.; Precipitation growth at a cold front. *Q J R Met Soc, London*, **99,** 1973, pp. 252–259.

KIRKPATRICK, W. A.; A sunshine sensor for automatic weather stations. Geneva, World Meteorological Organization, Commission for Instruments and Methods of Observation, 6th Session, Helsinki, Aug. 1973, CIMO VI, Scientific Discussions, 1973, pp. 16–21.

LANKESTER, J. D.; A simple summer index. *Weather, London*, **28,** 1973, p. 130.

LAWRENCE, E. N., B.Sc.; Air pollution, *New Scientist, London*, **58,** 1973, p. 124.

LAWRENCE, E. N., B.Sc.; Cyclonic-type rainfall and atmospheric mean-sea-level pressure over England and Wales. *Met Mag, London*, **102,** 1973, pp. 51–57.

LAWRENCE, E. N., B.Sc.; An example of extensive varied cirrus in the Austrian Tirol. *Met Mag, London*, **102,** 1973, pp. 120–121.

LAWRENCE, E. N., B.Sc.; Merle's weather observations. *Weather, London*, **28,** 1973, p. 127.

LAWRENCE, E. N., B.Sc.; Urban temperature trend analysis. *Weather, London*, **28,** 1973, pp. 170–171.

LAWRENCE, E. N., B.Sc.; Weekly weather cycles. *Bull Amer Met Soc, Lancaster, Pa*, **54,** 1973, p. 1034.

LEWIS, R. P. W., *see* MOORE, J. G. and LEWIS, R. P. W.

LUMB, F. E., M.Sc.; Upper tropospheric disturbances of the equatorial atmosphere and their influence on rainfall near the equator. *Met Mag, London*, **102,** 1973, pp. 269–272.

MCKERRELL, ELIZABETH A., *see* GLOYNE, R. W. and MCKERRELL, ELIZABETH A.

MCNAUGHTON, D., *see* HOWKINS, G. A., MCNAUGHTON, D. and ALDERSON, C.

MASON, B. D. and BRIDGE, G. C., *see* BRIDGE, G. C. and MASON, B. D.

MASON, B. J., C.B., D.Sc., F.R.S.; The contribution of satellites to the exploration of the global atmosphere and to the improvement of weather forecasting. *Meas & Control, London*, **6,** No. 11, 1973, pp. 441–451.

MASON, B. J., C.B., D.Sc., F.R.S.; The application of computers to weather forecasting. *Physics in Technology, London*, **4,** 1973, pp. 62–75.

MASON, B. J., C.B., D.Sc., F.R.S.; The GARP Atlantic Tropical Experiment. *Bull Wld Met Org, Geneva*, **22**, 1973, pp. 79–85.

MASON, B. J., C.B., D.Sc., F.R.S.; GARP Atlantic Tropical Experiment (GATE). *J Ceylon Met Soc, Colombo*, Jan. 1972, pp. 10–11.

MASON, B. J., C.B., D.Sc., F.R.S.; Growth habits of ice crystals. Comment on an article by LAMB, D. and HOBBS, P. V. (*J Atmos Sci*, Lancaster, Pa, **28**, 1971, pp. 1506–1509). *J Atmos Sci*, Lancaster, Pa, **30**, 1973, pp. 501–504.

MASON, B. J., C.B., D.Sc., F.R.S.; The new Richardson building of the Meteorological Office at Bracknell. *Bull Wld Met Org, Geneva*, **22**, 1973, pp. 25–27.

MASON, B. J., C.B., D.Sc., F.R.S.; Production of ice crystals in slightly supercooled cumulus. *Nature, London*, **245**, 1973, pp. 451–453.

MASON, B. J., C.B., D.Sc., F.R.S.; Some comments on weather modification. *Weather, London*, **27**, 1972, pp. 518–519. Also appears in: Quebec, Service de Météorologie, Feuillet Météorologique, Vol. 12, 1973, pp. 84–88.

MASON, B. J., C.B., D.Sc., F.R.S.; Speech of welcome to the cloud physics conference. *Bull Amer Met Soc, Lancaster, Pa*, **54**, 1973, pp. 101–103.

MASON, B. J., C.B., D.Sc., F.R.S.; The physics of cloud and precipitation. MCINTYRE, D. P. (editor); Meteorological challenges; a history. Ottawa, Information Canada, 1972, pp. 73–126.

MASON, P. J., *see* DOUGLAS, H. A. and MASON, P. J.

MAY, B. R., *see* CARRUTHERS, G. P., MAY, B. R., MILLER, D. E. and STEWART, K. H.

MEADE, P. J., O.B.E., B.Sc., A.R.C.S.; The history of the World Meteorological Organization with special reference to oceanography. *Mar Obsr, London*, **43**, 1973, pp. 25–31.

MILLER, D. E., B.A. and RYDER, P., Ph.D.; Measurement of the ozone concentration from 55 to 95 km at sunset. *Planet Space Sci, London*, **21**, 1973, pp. 963–940.

MILLER, D. E., *see* CARRUTHERS, G. P., MAY, B. R., MILLER, D.E. and STEWART, K. H.

MOORE, J. G., B.Sc. and LEWIS, R. P. W., M.A., M.Sc.; The probability of encountering radar weather-echo near Gan. *Met Mag, London*, **102**, 1973, pp. 185–205.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.; The Committee on Meteorological Effects of Stratospheric Aircraft (COMESA). Paris, Centre National de la Recherche Scientifique. Séminaire franco-britannique sur les conséquences des vols stratosphériques. COVOS/COMESA, Paris, 22–23 March 1973, Paris, 1973, Section I–4.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.; Review of the meteorological effects of stratospheric aircraft. Paris, Centre National de la Recherche Scientifique. Séminaire franco-britannique sur les conséquences des vols stratosphériques. COVOS/COMESA, Paris, 22–23 March 1973, Paris, 1973, Section I–2.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.; Upper atmosphere meteorology. MCINTYRE, D. P. (editor); Meteorological challenges: a history. Ottawa, Information Canada, 1972, pp. 127–156.

MURRAY, R., M.A.; Forecasting seasonal rainfall and temperature for England and Wales in spring and autumn from anomalous atmospheric circulation over the northern hemisphere. *Met Mag, London*, **102**, 1973, pp. 15–26.

NEWSON, R. L., B.A.; Development of a three-dimensional general circulation model for the study of stratospheric motions. Paris, Centre National de la Recherche Scientifique. Séminaire franco-britannique sur les conséquences des vols stratosphériques. COVOS/COMESA, Paris, 22–23 March 1973, Paris, 1973, Section VII–2.

NEWSON, R. L., B.A.; Response of a general circulation model of the atmosphere to removal of the Arctic ice-cap. *Nature, London*, **241**, 1973, pp. 39–40.

NEWSON, R. L., *see* GILCHRIST, A., CORBY, G. A. and NEWSON, R. L.

NEWSON, R. L., *see* GOLDSMITH, P., TUCK, A. F., FOOT, J. S., SIMMONS, E. L. and NEWSON, R. L.

NICHOLASS, C. A., *see* HARROLD, T. W., ENGLISH, E. J. and NICHOLASS, C. A.

NICHOLASS, C. A., *see* HARROLD, T. W., ENGLISH, E. J. and NICHOLASS, C. A.

NICHOLLS, J. M., B.Sc.; Aircraft measurements of disturbed airflow over mountains. *Weather, London*, **28**, 1973, pp. 141–152.

NICHOLLS, J. M., B.Sc., *in* MCPHERSON, A. and NICHOLLS, J. M.; Results of a series of flights in the stratosphere over mountainous terrain in the western U.S.A. during February, 1967. London, Aeronautical Research Council, Current Papers No. 1159. HMSO, London, 1971.

PAINTER, H. E., B.Sc.; The performance of wet-bulb thermometers in the Large Thermometer Screen. *Met Mag, London*, **102**, 1973, pp. 212–215.

PARDOE, C. W., *see* BROWNING, K. A., HARDMAN, M. E., HARROLD, T. W. and PARDOE, C. W.

PARDOE, C. W., *see* BROWNING, K. A. and PARDOE, C. W.

PARKER, D. E., B.Sc.; Equatorial Kelvin waves at 100 millibars. *Q J R Met Soc, London*, **99**, 1973, pp. 116–129.

PARKER, D. E., B.Sc.; On the variance spectra and spatial coherences of equatorial winds. *Q J R Met Soc, London*, **99**, 1973, pp. 48–55.

PARKER, D. E., B.Sc.; Tropospheric winds and the occurrence of rainfall near the equator. *Met Mag, London*, **102**, 1973, pp. 26–30.

PASQUILL, F., D.Sc. and SMITH, F. B., Ph.D.; The physical and meteorological basis for the estimation of the dispersion of windborne material. International Union of Air Pollution Prevention Associations, Proceedings of the 2nd International Clean Air Congress, Washington, D.C., Dec. 1970, 1971, pp. 1067–1072.

PHILPOTT, L. B., D.S.C., R.D., R.N.R.; Logbooks. *Mar Obsr, London*, **43**, 1973, pp. 191–198.

PRICHARD, R. J.; Diurnal variation of thunder at Manchester Airport. *Weather, London*, **28**, 1973, pp. 327–331.

RATCLIFFE, R. A. S., M.A.; The influence of tropical east Pacific Ocean temperatures on the atmosphere. Comment on an article by ROWNTREE, P. R. (*Q J R Met Soc, London*, **98**, 1972, pp. 290–321). *Q J R Met Soc, London*, **99**, 1973, p. 575.

RATCLIFFE, R. A. S., M.A.; Recent work on sea surface temperature anomalies related to long-range forecasting. *Weather, London*, **28**, 1973, pp. 106–108, 113–117.

RATCLIFFE, R. A. S., M.A., *in* LAMB, H. H. and RATCLIFFE, R. A. S.; On the magnitude of climatic anomalies in the oceans and some related observations of atmospheric circulation behaviour. Copenhagen, Conseil international pour l'exploration de la mer. Extrait des Rapports et Procès-verbaux, Vol. 162, Copenhagen, 1972, pp. 120–132.

RATCLIFFE, R. A. S. and COLLISON, P., *see* COLLISON, P. and RATCLIFFE, R. A. S.

RAYMENT, R., B.Sc.; An observational study of the vertical profile of the high frequency fluctuations of the wind in the atmospheric boundary layer. *Boundary Layer Met, Dordrecht*, **3**, 1973, pp. 284–300.

READINGS, C. J., Ph.D., D.I.C. *et alii*; The formation and breakdown of Kelvin–Helmholtz billows. *Boundary Layer Met, Dordrecht*, **5**, 1973, pp. 233–240.

READINGS, C. J., Ph.D., D.I.C.; Some aspects of the Cardington research programme. *Q J R Met Soc, London*, **99**, 1973, pp. 764–766.

READINGS, C. J., Ph.D., D.I.C., GOLTON, E. and BROWNING, K. A., Ph.D., D.I.C.; Fine-scale structure and mixing within an inversion. *Boundary Layer Met, Dordrecht*, **4**, 1973, pp. 275–287.

RICKETTS, J. N., B.Sc.; An investigation into a relationship between upper-air relative humidity and cloud cover. *Met Mag, London*, **102**, 1973, pp. 146–153.

RITCHIE, W. G., M.A. and VIRGO, S. E., O.B.E., M.Sc.; Embedded thermometers and forecasts of night minimum temperatures at Wyton. *Met Mag, London*, **102**, 1973, pp. 179–181.

ROBINSON, G. A. and CARRUTHERS, G. P., *see* CARRUTHERS, G. P. and ROBINSON, G. A.

ROBSON, M. E.; Deficiencies in shipboard observations. Geneva, World Meteorological Organization. Reports on Marine Science Affairs, No. 7, Geneva, 1973, pp. 76–81.

ROBSON, M. E.; Radio-sonde observations from merchant ships. Geneva, World Meteorological Organization. Reports on Marine Science Affairs, No. 7, Geneva, 1973, pp. 559–563.

RYDER, P., *see* MILLER, D. E. and RYDER, P.

SALTER, PAULINE M., B.Sc.; Areal rainfall analysis by computer. Geneva, World Meteorological Organization. Distribution of precipitation in mountainous areas, Vol. II, Geneva, 1972, pp. 497–509.

SANDERSON, R. M.; The alternating currents of the equatorial Indian Ocean. *Mar Obsr, London*, **43**, 1973, pp. 31–35.

SANDS, K. J. T., *see* BLACKWELL, M. J. and SANDS, K. J. T.

SAUNDERS, W. E., B.Sc.; Radiation fog and stratus formation and fog clearance in terms of geostrophic wind—some applications of wind measurements on a high mast. *Met Mag, London*, **102**, 1973, pp. 140–146.

SAWYER, J. S. M.A., F.R.S.; Numerical weather prediction within World Weather Watch—past, present and future. Geneva, World Meteorological Organization. Tenth anniversary of the World Weather Watch. Geneva, 1973.

SIMMONS, E. L., *see* GOLDSMITH, P., TUCK, A. F., FOOT, J. S., SIMMONS, E. L. and NEWSON, R. L.

SIMMONS, E. L., Ph.D. and HAMILTON, R. A., O.B.E., M.A., F.R.S.E.; Ozone as a stratospheric Lagrangian tracer. *Pure Appl Geophys, Basle*, **106–108**, 1973, pp. 1200–1207.

SMITH, F. B., Ph.D.; A scheme for estimating the vertical dispersion of a plume from a source near ground level. Brussels, NATO Committee on the Challenges of Modern Society. Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling, Paris, Oct. 2–3, 1972. Brussels, 1972, Chap. XVII.

SMITH, F. B., Ph.D. and JEFFREY, G. H.; The prediction of high concentrations of sulphur dioxide in London and Manchester air. Brussels, NATO Committee on the Challenges of Modern Society. Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling. Paris, Oct. 2–3, 1972. Brussels, 1972, Chap. XVIII.

SMITH, F. B., *see* CARSON, D. J. and SMITH, F. B.

SMITH, F. B., *see* PASQUILL, F. and SMITH, F. B.

SMITH, L. P., B.A.; The drain brain. *Agric Met, Amsterdam*, **11**, 1973, pp. 1–2.

SMITH, L. P., B.A.; The effect of weather, drainage efficiency and duration of spring cultivations on barley yields in England. *Outl Agric, London*, **7**, 1972, pp. 79–83.

SMITH, L. P., B.A., *in* DAVIES, R. R. and SMITH, L. P.; Forecasting the start and severity of the hay fever season. *Clinical Allergy, London*, **3**, 1973, pp. 263–267.

SMITH, L. P., B.A.; The importance of agroclimatology in the world of today. Geneva, World Meteorological Organization. Agroclimatology in the semi-arid areas south of the Sahara. Geneva, 1973, pp. 3–5.

SMITH, L. P., B.A., COCHRANE, J. and BAILEY, V.; The estimation of wheat and barley acreages in England by reference to the weather of the previous summer. *Met Mag, London*, **102**, 1973, pp. 265–269.

SMITH, L. P., B.A. and CROXALL, H. E.; Autumn weather and cereal growing in England. *ADAS Q Rev, London*, No. 8, 1973, pp. 177–183.

SMITH, L. P., B.A. and DAVIES, R. R.; Weather conditions and spore trap catches of barley mildew. *Pl Path, London*, **22**, 1972, pp. 1–10.

SMITH, L. P., B.A., *in* ALLEN, W. M. and SMITH, L. P.; When they die on the road. *Pig Farming Supplement, Ipswich*, Oct. 1973, pp. 81–82.

SMITH, L. P., B.A., *in* POLLEY, R. W. and SMITH, L. P.; Barley mildew forecasting. *Proc 7th British Insecticide and Fungicide Conf, Brighton, Nov.* 1973, Vol. 2, 1973, pp. 373–378.

STARR, J. R., Ph.D., D.I.C. and BROWNING, K. A., Ph.D., D.I.C.; Doppler radar measurements of clear air turbulence. *Proc 15th Radar Met Conf, Champaign-Urbana, Ill., Oct.* 1972. Boston, Mass, American Meteorological Society, 1972, pp. 148–251.

STARR, J. R., *see* BROWNING, K. A., STARR, J. R. and WHYMAN, A. J.

STARR, J. R., *see* BROWNING, K. A., BRYANT, G. W., STARR, J. R. and AXFORD, D. N.

STEWART, J. B., B.Sc., D.I.C. and THOM, A. S.; Energy budgets in pine forest. *Q J R Met Soc, London*, **99**, 1973, pp. 154–170.

STEWART, K. H., *see* CARRUTHERS, G. P., MAY, B. R., MILLER, D. E. and STEWART, K. H.

TABONY, R. C., *see* JONAS, P. R. and TABONY, R. C.

TAYLOR, P. J.; Note on a meso-scale convergence zone. *Weather, London*, **28**, 1973, pp. 476–477.

TEMPERTON, C., B.Sc.; Some experiments in dynamic initialization for a simple primitive equation model. *Q J R Met Soc, London*, **99**, 1973, pp. 303–319.

TONKINSON, B.; Use of precision aneroid barometers in the United Kingdom. Geneva, World Meteorological Organization, Commission for Instruments and Methods of Observation, 6th Session, Helsinki, Aug. 1973, CIMO VI, Scientific Discussions, 1973, pp. 16–21.

TUCK, A. F., *see* GOLDSMITH, P., TUCK, A. F., FOOT, J. S., SIMMONS, E. L. and NEWSON, R. L.

TYLDESLEY, J. B., B.A.; Long-range transmission of tree pollen to Shetland. *New Phytol, Cambridge*, **72**, 1973, pp. 175–181, 183–190, 691–697.

WALES-SMITH, B. G.; An analysis of monthly rainfall totals representative of Kew, Surrey from 1697 to 1970. *Met Mag, London*, **102**, 1973, pp. 157–171.

WALES-SMITH, B. G.; Evaporation in the London area from 1698 to 1970. *Met Mag, London*, **102**, 1973, pp. 281–291.

WHITE, G. A.; Special requirements for meteorologists to provide services to marine users and authorities concerned with marine problems. Geneva, World Meteorological Organization. Reports on Marine Science Affairs, No. 6, Geneva, 1973, pp. 56–59.

WHYMAN, A. J., *see* BROWNING, K. A., STARR, J. R and WHYMAN, A. J.

APPENDIX II

A SELECTION OF THE LECTURES AND BROADCASTS GIVEN BY MEMBERS OF THE STAFF

ANDREWS, J. B., Ph.D.

Availability of meteorological data. *Agricultural Development and Advisory Service. South Eastern Regional Agricultural Advisers Conference, Worthing.* 13 November.

Climate and navy beans. *Processors' and Growers' Research Organisation Conference, Maidstone.* 27 November.

ATKINS, MARGARET J., B.Sc.

Humidity analysis for a fine-mesh model. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 14 May.

ATKINS, N. J.

Contemporary aids to weather forecasting. *Leicester University Mathematical Society.* 1 May.

BEST, K. E. and SINGLETON, F., B.Sc., D.I.C.

Weather and Sailing. *Royal Meteorological Society course, Surbiton.* 3–6 September.

BEST, K. E.

Weather forecasting (your Weather Man). *Derbyshire Divisional Executive (Adult Education), Ripley.* 13 October.

BIRCH, L. S.

Meteorology for nuclear fallout prediction. *Home Office Group Warning Officers, Hove.* 19 April.

BLEASDALE, A., B.A., B.Sc.

Rainfall data: intensity-duration frequency analysis for storm water drainage design. *Planning and Transport Research and Computation Co. Ltd Course on Highway Drainage, London.* 29 May.

Planning and Transport Research and Computation Co. Ltd Seminar on Detailed Road Design, University of Sussex. 20 June.

BOYCE, JACQUELINE L. and DEEKS, P. H. G.

Recorded contribution to West German National TV programme on Grass Pollen forecasts on ATWS (by arrangement with the Post Office). 16 February.

BROWNING, K. A., Ph.D., D.I.C.

Mesoscale structure of rain systems in middle latitudes. *Sixth Session of the WMO Commission for Atmospheric Sciences, Versailles.* 27 November.

Fronts, waves and turbulence; radar reveals some of their mysteries. *Royal Meteorological Society Popular and Sixth Form Lecture, London.* 6 and 7 December.

BROWNSCOMBE, J. L., Ph.D.

A critical appraisal of the performance of air sampling used in the European Air Sampling Network. *WMO/WHO Technical Conference on the Observation and Measurement of Atmospheric Pollution, Otaniemi, near Helsinki.* 1 August.

BRYANT, J. D.

The use of meteorological parameters for nuclear fallout prediction. *Royal Observer Corps Officers, Llandudno.* 10 November.

BRYANT, K.

Further progress in the use of meteorological parameters for nuclear fallout prediction. *Conference of Home Office Chief Warning Officers and Sector Scientists, Moreton in Marsh.* 3 November.

BURRIDGE, D. M., Ph.D.

Weather. *Manchester and District Branch of the Physics Society, Manchester.* 22 January.

A semi-implicit integration scheme for a primitive equation model of the atmosphere. *Computational Mathematics and Applications Seminar, Oxford.* 15 March.

Implicit treatment of the faster moving gravity waves. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 18 May.

BUSHBY, F. H., B.Sc.

Weather data, analysis and forecasting. *DATAFAIR '73, Nottingham University.* 11 and 12 April.

CARSON, D. J., Ph.D.
A thermodynamic model for the development of a convectively unstable boundary layer. *Second IUTAM/IUGG Symposium on Turbulent Diffusion in Environmental Pollution, Charlottesville, Virginia.* 9 April.
A model for the development of a convectively unstable boundary layer. *Royal Meteorological Society Discussion Meeting, London.* 16 May.

COLLIER, C. G., B.Sc.
Laboratory experiments on flow over obstacles—an atmospheric application. *UNESCO Summer School on Mesoscale Atmospheric Phenomena, Venice.* 30 August.
Topographic effects in atmospheric systems. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 17 May.

CORNFORD, S. G., M.Sc.
Turbulence at medium and high flight levels. *AGARD/NATO Flight Mechanics Panel Symposium, Woburn Abbey, Beds.* 14 May.

CRABTREE, J., B.A.
The surveyor's atmosphere. *Land Surveyors Division, Royal Institution of Chartered Surveyors, London.* 15 November.

CULLEN, M. J. P., B.A.
The use of finite element methods for approximating meteorological equations in the horizontal. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 16 May.
The application of finite element methods to some non-linear evolutionary problems. *Oxford University Computer Laboratory.* 6 December.

DALTON, F.
Meteorology. *Course of 12 lectures to the Workers Educational Association, Stokenchurch, Bucks.* 20 February–5 June.

DAVIES, J. W.
Weather and the farmer. *Thornbury Branch of the National Farmers Union, Thornbury.* 4 December.

DORRELL, A. T.
The weather routeing of ships. *The Royal Institution of Naval Architects and the Institute of Marine Engineers, Portsmouth.* 6 December.

DORRELL, A. T. and MACKIE, G. V.
Practical experience of ship routeing. *Joint meeting Royal Meteorological Society/Institute of Navigation, Edinburgh University.* 15 March.

EDWARDS, BARBARA A.
The work of London Weather Centre.
National Federation of Business and Professional Women's Clubs, London. 6 February.
BBC Engineering Society, London. 4 December.

ENGLISH, E. J., B.Sc.
Characteristics of rainfall fields. *Construction Industry Research and Information Association Colloquium on Rainfall, Runoff and Surface Water Drainage of Urban Catchment, University of Bristol.* 3 April.

FISH, M. J.
Interview on BBC radio 'Today' programme about WMO Centenary Stamp Display at London Weather Centre. 22 September.

FORSDYKE, D., B.Sc.
Meteorological instrumentation and measurement. *British Society for Parasitology, London.* 30 October.
British climate and implications for South West agriculture. *South West Region Agricultural Advisers Conference, Torquay.* 23 November.

FOORD, H. V., PARKER, G. H. B., B.Sc. and OGDEN, R. J., B.Sc.
How weather forecasts are produced. *Weekend course at National Women's Institutes Denman College, Abingdon and H.Q. Bracknell.* 17–19 August.

FOORD, H. V.
Your weather service.
Institute of Building, Coventry. 24 January.
Institute of Printing, London. 14 April.
School of Pharmacy, University of London. 24 October.

GADD, A. J., Ph.D.
Computers in weather forecasting. *Lanchester Polytechnic, Rugby.* 1 March.
The role of the boundary layer in a numerical weather prediction model. *Imperial College, London.* 1 March.
An economic explicit integration scheme. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 18 May.

GOLDSMITH, P., M.A.
A comparison of nitrogen oxides produced by nuclear explosions and that expected by large fleets of Concordes. *NATO/AGARD Conference on Atmospheric Pollution by Aircraft, London.* 9 April.
Measurements of the size distribution of natural freezing nuclei and the efficiency of the membrane filter technique for submicron nuclei. *8th International Conference on Nucleation, Leningrad.* 27 September.
The production of submicron ice fragments by water droplets freezing in free fall or on accretion on an ice surface. *8th International Conference on Nucleation, Leningrad.* 27 September.
Stratospheric pollution. *Aeronautical Research Council, London.* 20 December.

GOODISON, C. E., C.Eng., M.I.E.R.E.
Meteorological Telecommunication Systems Engineering. *Institution of Electronics and Radio Engineers, London.* 16 May.

HARROLD, T. W., Ph.D., D.I.C.
Results from the Dee Weather Radar Project. *Joint Meteorological Office/Water Resources Board Colloquium on the Quantitative Measurement of Areal Rainfall by Radar, Reading.* 13 December.

HASTINGS, J. D., B.Sc.
Operational use of weather. *Royal Military College of Science, Shrivenham.* 17 July.

HAYES, F. R., B.A.
Assessment of model behaviour. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 18 May.

HIDE, R., Sc.D., F.R.S.
Jupiter and Saturn. *Royal Society, London.* 25 January.
Recent work on rotating fluids. *Imperial College, London.* 14 March.
Motions in planetary atmosphere.
Service d'Aeronomie, Paris. 30 March.
Queen Mary College, London. 2 May.
Cambridge University Astronomical Society. 26 October.
Durham University Astronomical Society. 15 November.
Geostrophic lift and drag. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 16 May.
Review of recent work on the dynamics of Jupiter's atmosphere. *IAU Extraordinary General Assembly, Torun, Poland.* 7 September.

HUGHES, I. G.
Meteorology for nuclear fallout prediction. *Home Office Group Warning Officers, Norwich.* 9 May.

HULL, O. M.
Meteorology for yachtsmen. *Course of 15 lectures to the Inner London Education Authority (Adult Education section) aboard the Cutty Sark at Greenwich.* 24 September–31 December.
Elementary meteorology. *Course of 6 lectures to the Workers Educational Association, Cuffley, Herts.* 27 September–1 November.

HUNT, G. E., Ph.D., F.I.M.A.
Contribution to BBC World Service programme 'Science in Action' concerning the atmosphere of Jupiter and Saturn. 10 January.
Contribution to BBC Radio 4 programme 'World Tonight' concerning meteorology of Jupiter and Saturn. 15 January.
Contribution to BBC World Service programme 'Discovery' on studying weather on Jupiter and Saturn. 15 March.

A new look at the Martian atmosphere. *Royal Society, London.* 12 May.

Structure and composition of the atmosphere and clouds of Jupiter. *National Center for Atmospheric Research, Boulder, Colorado.* 19 July.

The atmosphere of Jupiter and Saturn. *European Geographical Society, Zurich.* 25 September.

Radiative properties of terrestrial clouds at visible and thermal infra-red window wavelengths. *Royal Meteorological Society, London.* 17 October.

JACKSON, M. C., M.Sc.

Rainfall depth-duration-return period analysis. *Institute of Municipal Engineers, Aston University.* 11 October.

JOHNSON, G. C.

Meteorology and mountain climbing. *Course of 3 lectures to Mountain Expedition Training Centre, Brent, Middx.* 25 March–9 May.

JONCKHEERE, C. G. de

Measurement of stratospheric water vapour by the absorption of solar infra-red. *Conference on Spectroscopy in Environmental Studies, Aberdeen University.* 26 June.

JONES, D. E., B.Sc.

The use of computers in weather forecasting. *Bristol Branch of the British Computer Society.* 14 February.

KEERS, J. F., B.Sc.

Precipitation, its measurement and instrumentation. *Middlesex Polytechnic.* 1 November.

LAMBLEY, A.

Upper wind forecasts for nuclear fallout prediction. *Home Office Group Warning Officers, Bath.* 6 November.

MCKELLAR, H. A.

Forecasting for pigeon racing. *Scottish Homing Union, Bathgate, West Lothian.* 14 February.

MASON, B. J., C.B., D.Sc., F.R.S.

The physics of the thunderstorm. *Chemical and Physical Society, University College, London.* 20 February.

The use of numerical models in the forecasting of weather and climate. *Civil Service College, Sunningdale, Berks.* 5 March.

The physics of the thunderstorm. *Department of Geophysics, Reading University.* 16 March.

The Global Atmospheric Research Programme. *13th International Technical and Scientific Meeting on Space, Rome.* 22 March.

The place of science in the present and the future. *Speech Day at Ranelagh School, Bracknell.* 18 May.

The Global Atmospheric Research Programme and the future of weather forecasting. *British Association for the Advancement of Science, Canterbury.* 22 August.

The contribution of satellites to the exploration of the global atmosphere and to the improvement of weather forecasting. *The Thomson Lecture of the Institute of Measurement and Control, Royal Institution, London.* 2 October.

New concepts and techniques in meteorology as an international science. *The History of Ideas Club, Reading University.* 18 October.

Work and future plans of the Meteorological Office. *Parliamentary and Scientific Committee, House of Commons, Westminster.* 23 October.

Weather forecasting in the computer and satellite age and its application to agriculture and industry. *National Institute for Research in Dairying, Reading.* 15 November.

MASON, P. J., Ph.D.

Forces on bodies moving transversely through a rotating fluid.
British Theoretical Mechanics Colloquia, University of Surrey, Guildford. 5 April.
Department of Mathematics, University College, London. 19 November.

Sloping convection in a container with sloping end-walls.
Geophysical Fluid Dynamics Institute, Florida State University, Tallahassee, Florida. 9 April.
Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Mass. 13 April.

MEADE, P. J., O.B.E., B.Sc.

The role of meteorology in the use of oceans. *WMO Centenary Celebrations, Geneva.* 11 September.

MORRIS, R. M., B.Sc.

Modern methods in forecasting. *Southampton University Maritime Society.* 12 March.

MURRAY, R., M.A.

Seasonal weather and anomalous atmospheric circulation. *Climatic Research Unit, University of East Anglia, Norwich.* 22 June.

Meteorological applications of radar-based rainfall data. *Joint Meteorological Office/ Water Resources Board Colloquium on Quantitative Measurement of Areal Rainfall by Radar, Reading.* 13 December.

NEWSON, R. L., B.A.

Contribution to the BBC World Service programme 'Discovery' concerning results of a simulation of the atmosphere's general circulation in the absence of the Arctic ice-cap. 31 January.

Development of a three-dimensional general circulation model for the study of stratospheric motions. *COVOS/COMESA French-British Seminar on the Meteorological Effects of Stratospheric Aircraft, Paris.* 23 March.

OGDEN, R. J., B.Sc.

Weather forecasting and Public Service applications. *British Association of Young Scientists, Canterbury.* 7 March.

Recent developments in weather forecasting. *Geographical Association Central London Branch.* 22 March.

Recorded contribution to BBC Radio 3 programme on Ship Routeing and Off-shore Industry Forecasting. 25 April.

Recorded contribution to BBC Overseas Service programme on meteorology. 16 May.

Weather, waves and North Sea oil. *Joint meeting of the Royal Meteorological Society, Scottish Branch and the Department of Coastal Engineering, Heriot-Watt University, Edinburgh.* 7 November.

PARDOE, C. W., B.Sc.

Modern methods of meteorological research. *N.F.U. & Avon Mutual Insurance Institute, Stratford upon Avon.* 17 January.

PARKER, B. N.

Persistence of atmospheric features during the period October 1971 to March 1972. *University of East Anglia, Norwich.* 21 February.

PARKER, G. H., B.Sc.

Weather forecasting and its application to broadcasting. *Institute of Heating and Ventilating Engineers, London.* 18 September.

PASQUILL, F., D.Sc.

Limitations and prospects in the estimation of dispersion on a regional scale. *Second IUTAM/IUGG Symposium on Turbulent Diffusion in Environmental Pollution, Charlottesville, Virginia.* 9 April.

The basis and limitations of estimates of pollution from meteorological data. *Nordic Symposium on Urban Air Pollution Modelling, Vedbaek, Denmark.* 5 October.

PETTIFER, R. E. W., B.Sc.

A laser radar for Raman scattering studies of the upper atmosphere. *Conference on Spectroscopy in Environmental Studies, Aberdeen University.* 26 June.

RATCLIFFE, R. A. S., M.A.

Climatic change. *Interview by Peter Fairley for ITN News.* 30 March.

Forecasting the weather. *Contribution to BBC World Service programme, together with Dr B. J. Mason and Mr R. J. Ogden.* 14 May.

RAYMENT, R., B.Sc.

A case study of structure and energetics of an inversion. *Symposium on the Atmospheric Boundary Layer, Association of German Meteorological Societies, Mainz.* 10 October.

Turbulence studies from a tethered balloon. *Reading University Seminar.* 26 October.

READINGS, C. J., Ph.D., D.I.C.

A case study of the structure and energetics of a subsidence inversion. *Seminar at Meteorological Laboratory, Air Force Cambridge Research Laboratories, Bedford, Mass.* 6 April.

The vertical component of turbulence in convective conditions. *Second IUTAM/ IUGG Symposium on Turbulent Diffusion in Environmental Pollution, Charlottesville, Virginia.* 9 April.

Some aspects of the Cardington research programme. *Royal Meteorological Society Discussion Meeting, London.* 16 May.

The Minnesota Experiment. *A short broadcast televised by the local television station at Grand Forks, N. Dakota.* 23 September.

RIDER, N. E., D.Sc.
The Global Atmospheric Research Programme Atlantic Tropical Experiment. *Bath University.* 7 April.

ROACH, W. T., Ph.D., D.I.C.
A field study of radiation fog. *Faraday Symposium on Smokes and Fogs, Swansea.* 30 March.

ROWNTREE, P. R., B.A.
Effects of sea-surface temperature anomalies in the tropics on the general circulation. *Study Conference on the Modelling Aspects of GATE, Tallahassee, Florida.* 26 January.

RYDER, P., Ph.D.
The physics of thunderstorm electrification. *Hampstead Scientific Club, London.* 27 September.

SAKER, N. J., M.Sc.
The computer in weather forecasting. *Oxford Polytechnic.* 19 March.

SAWYER, J. S., M.A., F.R.S.
Effects on pollution on atmospheric behaviour. *Conference Teach-in. 'The Atmosphere and Man', Imperial College, London.* 3 January.
Can industry and engineering affect our climate? *Symposium 'Engineering Tomorrow's Environment', Institution of Public Health Engineers, London.* 22 March.
Weather forecasting—its past and future. *IMO/WMO Centenary Conference, Vienna.* 4 September.

SCORER, E. A., B.A.
Clouds and Weather. *British Association of Young Scientists, Newcastle University.* 2 February.

SCOTT, J.
Your weather service. *Luton Scientific Society.* 10 October.

SHAW, D. B., B.Sc.
Whither the weather—towards better forecasting. *Kent Branch of the British Computer Society, Chatham.* 3 October.

SIMMONDS, E. L., M.A., Ph.D.
Measurement of aerosol absorption. *COVOS/COMESA French-British Seminar on Meteorological Effects of Stratospheric Aircraft, Paris.* 23 March.

SMITH, F. B., Ph.D.
The evaluation of atmospheric dispersion. *Hydraulics Research Station, Wallingford, Berks.* 23 January.
Atmospheric turbulence and diffusion and their influence on pollution. *The von Karman Institute for Fluid Dynamics, Brussels.* 9 May.
Forecasting urban pollution. *Royal Meteorological Society Summer Meeting, Reading.* 13 July.
Dispersion of pollution in the atmosphere.
Environmental Protection Agency, Research Triangle Park, Raleigh, N. Carolina. 25 October and 8 November.
Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee. 1 November.
Air Resources Laboratory, Silver Spring, Maryland. 16 November.
Basic theories of turbulence.
Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee. 2 November.
Penn State University, Pennsylvania. 15 November.
Atmospheric pollution. *The Welsh Branch of the Royal Meteorological Society, Cardiff.* 28 November.

SMITH, C. V., M.A., B.Sc.
Meteorology. *Pierse School, Cambridge.* 12 February.
Weather factors affecting the moisture content of standing grain and the time available for combining. *International Symposium on Moist Grain Storage, Paris.* 5 March.
Air movement and farm buildings. *Farm Buildings Association Symposium, Leamington Spa.* 14 March.
Winter weather and the growth of young beef cattle. *British Society for Animal Production, Harrogate.* 28 March.
Farm buildings. *Nottingham University Easter School.* 12 April.

SMITH, L. P., B.A.
Weather and disease. *Almroth Wright Lecture, St Mary's Hospital, London.* 21 May.
Meteorological factors of importance in biological systems (Chairman's address). *British Society for Parasitology, London.* 30 October.
Weather and animal diseases. *Research Group, Central Veterinary Laboratory, Weybridge, Surrey.* 14 November.
Micro, meso and macroclimate. *Postgraduate Students Course, Reading University.* 26 November.
Weather and disease. *Course in bacteriology, London Hospital.* 13 December.

STARR, J. R., Ph.D., D.I.C.
Physics of rain, snow and hail.
Lancaster University Scientific Society. 25 January.
Oxford University Scientific Society. 9 February.
Why does it rain?
Leicester University Geography Department. 6 March.
Nottingham University Physical Society. 22 November.
Clouds, rain and rainmaking.
Physical Society, Loughborough University of Technology. 5 March.
Bedford College Mathematics and Physical Society, London. 22 October.
Reading University Physical Society. 25 October.

TEMPERTON, C., B.Sc.
Some experiments in dynamic initialization. *WMO/IAMAP Symposium on Mesoscale Meteorological Systems and Fine Mesh Modelling, Reading.* 14 May.

THOMPSON, N., Ph.D.
Chemical threat to civilian populations. *Eastern Region Conference for Scientific Advisers, Cambridge.* 15 December.

TUCK, A. F., Ph.D.
Perturbations in stratospheric ozone concentrations. *COVOS/COMESA French-British Seminar on the Meteorological Effects of Stratospheric Aircraft, Paris.* 22 March.

TYLDESLEY, J. B., B.A.
Pollen transport to Shetland. *Quarternary Discussion Group, Cambridge.* 16 February.
Light in horticulture. *Regional Horticultural Advisers' Conference, Harrogate.* 7 March.
Work of Meteorological Office for Agriculture. *Agricultural Development and Advisory Service staff, Leeds.* 3 April.
Pollen transport.
Royal Meteorological Society, London. 21 November.
Colloquium, School of Agriculture, Sutton Bonington (University of Nottingham). 27 November.

WALES-SMITH, B. G.
An analysis of monthly rainfall totals representative of Kew, Surrey, from 1697 to 1970. *Climatological Discussion Group meeting on Trends in precipitation and snow occurrences over the British Isles, Oxford.* 7 September.
Rainfall data: intensity-duration-frequency analysis. *Planning and Transport Research and Computation Co. Ltd Course on High Drainage Design, London.* 26 November.

WHITE, G. D.
Weather study. *Course of 6 lectures to Workers Educational Association. Holyhead,* October/November.

WHITE, P. W., Ph.D.
Finite difference methods in weather prediction. *Department of Engineering, Leicester University.* 1 March.

YOUNG, W. B.
A background of Meteorology and the effect of meteorological parameters on nuclear fallout prediction. *Home Office Group Warning Officers and Royal Observer Corps Officers at:*
Turnhouse. 4 April
Dundee. 5 April
Aberdeen. 9 April
Inverness. 10 April
Ayr. 12 April

APPENDIX III

PUBLICATIONS

The publications prepared by the Meteorological Office are generally issued by Her Majesty's Stationery Office as official publications. Catalogues listing all the publications which may be purchased through the sales offices or usual agents of Her Majesty's Stationery Office, or direct from the Meteorological Office at Bracknell, are sent free to any applicant.

The following publications have been issued:

PERIODICAL

Annual Report on the Meteorological Office 1972.

Daily Aerological Record containing information in respect of meteorological conditions in the upper air for the British Isles.

Daily Weather Report containing weather maps for the northern hemisphere, British Isles, etc., and data.

Daily Weather Report, Overseas Supplement containing surface and upper air data (to 18 August 1971).

Monthly Summary of the *Daily Weather Report.*

Monthly Weather Survey and Prospects, a monthly publication containing climatological data for the United Kingdom, the weather of the past month, a general survey and inference, and weather prospects for the coming month in the United Kingdom; a supplementary document, containing survey, inference and prospects only, is published in mid-month.

Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain, a seasonal fortnightly publication providing estimates of soil moisture deficit in map form and as a tabular statement for river authority areas.

Sea Ice Charts (daily).

Monthly (coloured) Ice Maps (to February 1973).

Meteorological Magazine (monthly).

Monthly Weather Report (to March 1973).

Marine Observer (quarterly).

British Rainfall—annual volume for 1966.

Marine climatological summaries for the Atlantic Ocean east of 50°*W and north of* 20°*N*—1963, 1965 and 1966.

SERIAL

Geophysical Memoirs:

Volume XVI

118. Northern hemisphere monthly and annual mean sea-level pressure distribution for 1951–66 and changes of pressure and temperature compared with those of 1900–39, by H. H. Lamb, M.A., P. Collison, B.Sc., and R. A. S. Ratcliffe, M.A.

Volume XVII

119. A climatology of the stratosphere over north-west Europe, by R. A. Hamilton, O.B.E., M.A., F.R.S.E., B. D. Mason, B.Sc. and G. C. Bridge.

OCCASIONAL

Tables of temperature, relative humidity, precipitation and sunshine for the world, Part III (1973)—*Europe and the Azores.*

Aeronautical climatological summaries (WMO Models, A, B, C, C′, D, K and T) for Manchester Airport (1972). Period 1960–69.

Printed in Scotland for Her Majesty's Stationery Office by D. J. Clark Ltd., Glasgow.
Dd 506520 K9 5/74

HER MAJESTY'S STATIONERY OFFICE
Government Bookshops
49 High Holborn, London WC1V 6HB
13a Castle Street, Edinburgh EH2 3AR
41 The Hayes, Cardiff CF1 1JW
Brazennose Street, Manchester M60 8AS
Southey House, Wine Street, Bristol BS1 2BQ
258 Broad Street, Birmingham B1 2HE
80 Chichester Street, Belfast BT1 4JY
Government publications are also available through booksellers

ISBN 0 11 400286 X